PHILOSOPHY

PECK'S GANOT

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REVISED EDITION.

INTRODUCTORY COURSE

OF

NATURAL PHILOSOPHY

FOR THE USE OF

HIGH SCHOOLS AND ACADEMIES.

EDITED FROM

GANOT'S POPULAR PHYSICS.

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PREFACE TO THE REVISED EDITION.

THE revision of "Peck's Ganot" was begun by Mr. BURBANK in the spring of 1880, and completed by him as far as the subject of "Ballooning," on page 164, when the progress of the work was interrupted by his death. The revision of the remaining portions is my own work.

The essential characteristics and general plan of the book have, so far as possible, been retained, but at the same time many parts have been entirely rewritten, much new matter added, a large number of new cuts introduced, and the whole treatise thoroughly revised and brought into harmony with the present advanced stage of scientific discovery.

Among the new features designed to aid in teaching the subject-matter, are the summaries of topics, which, it is thought, will be found very convenient in short reviews.

As many teachers prefer to prepare their own questions on the text, and many do not have time to spend in the solution of problems, it has been deemed expe-

dient to insert both the review questions and problems at the end of the volume, to be used or not at the discretion of the instructor.

I desire to acknowledge my obligations to all who have in any way given me aid and advice in the preparation of this revision, and especially to Professor PECKHAM, of Adelphi Academy, Brooklyn, N. Y., who has kindly looked over many of the proof-sheets, and furnished me with valuable suggestions.

J. I. HANSON

WOBURN, July, 1881.

EDITOR'S PREFACE.

THE rapid spread of scientific knowledge, and the continually widening field of its application to the useful arts, have created an increased demand for new and improved text-books on the various branches of NATURAL PHILOSOPHY.

Of the elementary works that have appeared within a few years, those of M. GANOT stand pre-eminent, not only as popular treatises, but as thoroughly scientific expositions of the principles of PHYSICS. His "Traité de Physique" has not only met with unprecedented success in France, but has been extensively used in the preparation of the best works on Physics that have been issued from the American press.

In addition to the "Traité de Physique," which is intended for the use of Colleges and higher institutions of learning, M. GANOT has recently published a more elementary work, adapted to the use of schools and academies, in which he has faithfully preserved the prominent features and all the scientific accuracy of the larger work. It is characterized by a well-balanced

distribution of subjects, a logical development of scientific principles, and a remarkable clearness of definition and explanation. In addition, it is profusely illustrated with beautifully executed engravings, admirably calculated to convey to the mind of the student a clear conception of the principles unfolded. Their completeness and accuracy are such as to enable the teacher to dispense with much of the apparatus usually employed in teaching the elements of Physical Science.

In preparing an American edition of this work on Popular Physics, it has not been the aim of the editor to produce a strict translation. No effort, however, has been spared to preserve throughout, the spirit and method of the original work. No changes have been made, except such as have seemed calculated to harmonize it with the system of instruction pursued in the schools of our country.

By a special arrangement with M. Ganot, the American publishers are enabled to present *fac-simile* copies of all the original engravings.

New York, June 1, 1860.

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ELEMENTARY PHYSICS.

CHAPTER I.

PROPERTIES OF MATTER.

SECTION I. — DEFINITIONS AND GENERAL PROPERTIES OF MATTER.

1. **Physics — Physical Agents.** — NATURAL PHILOSOPHY, OR PHYSICS, treats of the general properties of bodies, and of the causes that modify these properties without altering their constitution.

The principal causes that modify the properties of bodies are: *Gravitation*, *Heat*, *Light*, and *Electricity*. These causes are called *Physical Agents* or *Forces*.

2. **A Body** is a collection of material particles; as a stone, or a block of wood. A body which is exceedingly small is called a *Material Point*.

3. **Molecules and Atoms.** — Bodies are made up of small particles, called *Molecules*, and these again are composed of still smaller elements, called *Atoms*.

A molecule is the smallest particle of matter that can exist by itself.

An atom is the smallest particle of matter that can exist in combination.

A molecule may consist of two or more atoms of the same kind of matter, or it may be composed of several atoms of different kinds; thus, a molecule of sulphur is a combination of two atoms of sulphur,

but a molecule of common salt consists of an atom of the metal sodium combined with an atom of chlorine.

Atoms are joined and held together by a kind of attraction called *chemical affinity.*

Molecules are kept in place by the action of two opposing forces, *molecular attraction* and *molecular repulsion.*

4. Mass and Density. — The MASS of a body is the quantity of matter which it contains.

The DENSITY of a body is the degree of closeness of its particles.

Different bodies, having the same volume, contain very different quantities of matter; for example, a cubic inch of lead contains nearly eleven times as much matter as a cubic inch of water. The masses of bodies are proportional to their weights.

Those bodies in which the particles are close together are said to be *dense;* thus, platinum and mercury are *dense* bodies. Those in which the particles are not close together are said to be *rare;* thus, steam and air are *rare* bodies. The densities of bodies having the same bulk are proportional to their weights.

5. Three States of Bodies. — Bodies may exist in three different states, *solid*, *liquid*, and *aeriform.*

SOLID bodies tend to retain a permanent form, because their molecules are held together by forces of attraction which are greater than the repellent forces that would tend to separate them.

In LIQUIDS the attractive and repellent forces are nearly balanced, and their molecules move freely among one another. Liquids have no tendency to retain a permanent form, but assume at once the form of the containing vessel.

In AERIFORM bodies the repellent are more powerful than the attractive forces, and their molecules constantly tend to separate and occupy a greater space. *Air* and all *gases* and *vapors* are examples of aeriform bodies.

The term FLUID is applied to both liquid and aeriform bodies.

Many bodies may exist in every one of the three states in succession. Thus, if ice be heated until the repellent forces balance those of at-

traction, it passes into the liquid state and becomes water; if still more heat be applied, the repellent forces prevail over those of attraction, and it passes into the state of vapor and becomes *steam.*

GENERAL PROPERTIES OF BODIES.

6. The most important properties which all bodies possess are: Extension, Weight, Impenetrability, Inertia, Porosity, Divisibility, Compressibility, Expansibility, and Elasticity.

7. Extension is the property by virtue of which a body occupies space.

MAGNITUDE and FORM depend upon Extension.

To occupy space a body must have the three dimensions, length, breadth, and thickness. The space occupied by a body is called its volume.

8. English Measures. — For the purpose of measuring the dimensions of bodies a standard unit of length is needed.

In England and the United States the *yard* has been adopted as the standard unit, and with its divisions and multiples is in common use.

9. The Metric System. — This system is in general use in France and in most of the countries of Europe.

It is adopted by scientific writers everywhere, and will probably soon come into general use throughout the civilized world. Its use in the United States has been legalized by act of Congress.

The unit of this system is the *meter*, which is the ten-millionth part of a quadrant of that meridian of the earth which passes through Paris. It is equal to 39.37 inches, nearly.

Its divisions and multiples vary in a tenfold ratio, and from these all the measures of surface, volume, and weight are derived. The nomenclature is derived from the Greek and Latin numerals. The Greek prefixes deka (10), hekto (100), kilo (1000), and myria (10,000), are used for the *multiples*, and the Latin prefixes deci ($\frac{1}{10}$), centi ($\frac{1}{100}$), milli ($\frac{1}{1000}$), are used for the *divisions* of the unit.

10. Metric Measures of Length. — In the following table the several denominations of linear measure are given

in their order, with the English equivalents, and the abbreviations used.

1 Millimeter	(mm.)	= 0.001	m. =	0.03937	inch
1 Centimeter	(cm.)	= 0.01	m. =	0.3937	"
1 Decimeter	(dm.)	= 0.1	m. =	3.937	"
1 *Meter*	(m.)	= 1.	m. =	39.37	"
1 Dekameter	(Dm.)	= 10	m. =	393.7	"
1 Hektometer	(Hm.)	= 100	m. =	328 ft. 1 in.	
1 Kilometer	(Km.)	= 1000	m. =	3280 ft.	
1 Myriameter	(Mm.)	= 10000	m. =	6.2137	miles

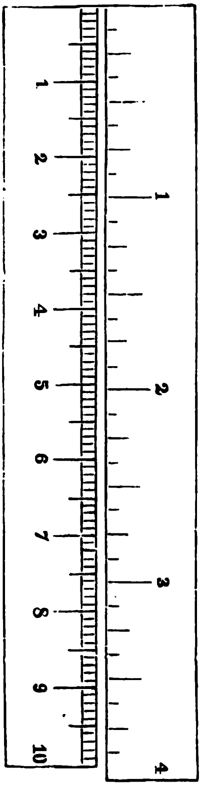

Fig. 1.

In the figure in the margin one decimeter is compared with a scale of inches. It will be seen that the decimeter is a little less than 4 inches.

With the square meter and the cubic meter as units, tables are constructed for the measures of surface and volume, in the same way as with the English measures; the ratio 100 (10^2) being used for surface measures, and 1000 (10^3), for volumes.

Thus, 100 square millimeters = 1 square centimeter, etc.; 1000 cubic millimeters = 1 cubic centimeter, etc.

11. Measures of Capacity. — For measuring articles which by the English system are sold by dry or liquid measure, the unit adopted is the *liter*, which is equal to one cubic decimeter.

The denominations are as follows. Ratio 10.

1 Milliliter	(ml.) =	1 cubic centimeter	
1 Centiliter	(cl.) =	10 "	"
1 Deciliter	(dl.) =	100 "	"
1 *Liter*	(l.) =	1000 "	"
1 Dekaliter	(Dl.) =	10 "	decimeters
1 Hektoliter	(Hl.) =	100 "	"
1 Kiloliter	(Kl.) =	1 "	meter

The liter is equal to 1.0567 liquid quarts, or 0.908 of a dry quart. It may therefore be used conveniently in place of both.

12. Weight. — A body falls, when not supported, because it is attracted toward the centre of the earth. When it rests upon another body or upon the surface of the earth, its tendency to fall is not destroyed, and it presses downward with a force proportioned to the degree in which it is attracted.

Hence weight is the *measure of the earth's attraction.* The term weight is commonly used in this limited sense, but, since the attraction of gravitation is universal, a body would have weight if placed on or near the surface of any of the planets or other heavenly bodies.

The unit of weight in the English system is the avoirdupois pound of 7000 grains. In the Metric System the unit adopted is the *gram,* which is the weight of one cubic centimeter of distilled water at its greatest density, that is, at the temperature of 39.2° Fahrenheit or 4° Centigrade.

13. Metric Table of Weight. — Ratio 10.

One Milligram	(mg.)	=	0.0154	grain	
" Centigram	(cg.)	=	0.1543	"	
" Decigram	(dg.)	=	1.5432	"	
" *Gram*	(g.)	=	15.432	"	
" Dekagram	(Dg.)	=	0.3527	ounce	av.
" Hektogram	(Hg.)	=	3.5274	"	"
" Kilogram	(Kg.)	=	2.2046	pounds	av.
" Myriagram	(Mg.)	=	22.046	"	"
" Quintal	(Q.)	=	220.46	"	"
" Tonneau	(T.)	=	2204.6	"	"

14. Impenetrability is that property by virtue of which no two bodies can occupy the same place at the same time. This property is self-evident, although phenomena are observed which would seem to conflict with it. Thus, when a pint of alcohol is mixed with a pint of water, the volume of the resulting mixture is less than a quart. This diminution of volume arises from the particles of one of the fluids insinuating themselves between those of the other; but it is clear

that where a particle of alcohol is, there a particle of water cannot be.

It may be shown by several simple experiments that air and water cannot occupy the same space. Invert a glass tumbler and press it downward into a vessel of water. The water will not enter and fill the tumbler. Close one end of a glass tube with the thumb and thrust the other end into the water. The water cannot fill the tube while the air is retained. Remove the thumb so that the air can escape, and the water will immediately rise and fill the tube. Pass a funnel through a cork fitted air-tight to a bottle. Let a bent tube pass through another hole in the cork, and at the other end dip into a tumbler of water, as shown in Fig. 2. If then water is poured into the funnel, as fast as it enters the bottle air will escape in bubbles from the end of the tube in the tumbler.

Fig. 2.

15. Inertia is the tendency which a body has to maintain its state of rest or motion. If a body is at rest it has no power to set itself in motion, or if it is in motion it has no power to change either its rate of motion or the direction in which it is moving. Hence, if a body is at rest, it will remain at rest, or if in motion, it will move on uniformly in a straight line until acted upon by some force.

The reason why we do not see bodies continue to move on uniformly in straight lines, when set in motion, is that they are continually acted upon by forces which change their state of motion. Thus, a ball thrown from the hand, besides meeting with the resistance of the air, is continually drawn downwards by the attraction of the earth, till at last it is brought to rest.

Many familiar phenomena are explained by the principle of inertia. For example, when a vehicle in motion is suddenly arrested, loose articles in it are thrown to the front, because they tend to keep the motion which they had acquired.

If a person jumps from a car in rapid motion, he is likely to be thrown violently to the ground; for his body retains its onward motion, while his feet are stopped by striking the ground.

Let a card with a coin placed upon it be balanced on one of the fingers of the left hand; then snap it suddenly with the middle finger of the right hand, as represented in Fig. 3. If struck evenly and carefully the card will fly away, leaving the coin balanced upon the finger. In this experiment the inertia of the coin is not overcome by the slight friction of the card, and it therefore remains nearly where it was first placed on the finger.

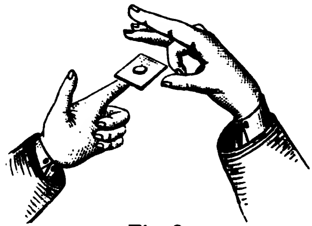

Fig. 3.

16. Porosity is that property of a body by which spaces exist between its molecules.

All bodies are more or less porous.

Actual cavities or cells that are visible are called *Sensible Pores*. The invisible spaces that separate all the molecules of a body are called *Physical Pores*.

The metals, in which no pores can be seen even by the aid of the most powerful microscope, are shown to be porous by the fact that by great pressure liquids and gases may be made to pass through them.

17. Divisibility.—All bodies are capable of being divided and subdivided; and in many cases the parts that may be obtained are of almost inconceivable minuteness.

The following examples serve to show the extreme smallness of the molecules of matter. A single grain of carmine imparts a sensible color to a gallon of water; this gallon of water may be separated into a million of drops, and if we suppose each drop to contain ten particles of carmine, which is a low estimate, we shall have divided the grain of carmine into ten millions of molecules, each of which is visible to the naked eye.

The microscope reveals to us, in certain vegetable infusions, *animalcules* so small that several hundreds of them can swim in a drop of water that adheres to the point of a needle. These little animals are capable of motion, and even of preying upon each other; they therefore possess organs of motion, digestion, and the like. How minute, then, must be the molecules which go to make up these organs!

A grain of musk is capable of diffusing its odor through an apartment for years, with scarcely an appreciable diminution of its weight. This shows that the molecules of musk continually given off to replenish the odor are of inconceivable smallness.

The blood of animals consists of minute red globules swimming in a serous fluid; these globules are so small that a drop of human blood no larger than the head of a small pin contains at least 50,000 of them. In many animals these globules are still smaller; in the musk deer, for example, a single drop of blood of the size of a pin's head contains at least a million of them.

18. **Compressibility** is the property of being reduced to a smaller space by pressure. This property is a consequence of porosity, and the change of bulk comes from the particles being brought nearer together by the pressure. Sponge, india-rubber, cork, and elder-pith are examples of compressible bodies; they may be sensibly diminished in volume by the pressure of the fingers. Gases are, however, the best examples of compressible bodies.

Some of the gases may be reduced to liquids by pressure alone; and recent experiments have proved that all the gases known can be liquefied by great pressure and intense cold combined.

Liquids are but slightly compressible; but careful experiments have shown that they yield somewhat to great pressure.

Metals are compressible, as is shown in the process of stamping coins, medals, and the like.

19. **Expansibility** is the property which a body possesses of increasing in bulk or volume under certain circumstances.

All bodies expand on being heated.

Gases expand most, liquids next, and solids least, when subjected to the same degree of heat. The molecules of air and the gases constantly repel each other, so that these substances have a continual tendency to increase in volume, even without the influence of heat.

The following experiment illustrates this property of air. A small rubber bag, nearly empty and fastened at the neck with a stop-cock, is placed under the receiver of an air-pump. Then let the air be

pumped out from the receiver, so that it no longer exerts pressure on the *outside* of the bag, and the air *within* will expand and fully inflate the bag.

Other examples of expansibility will be given hereafter in illustrating the effects of heat.

Fig. 4.

20. Elasticity is the property which bodies possess of recovering their original shape and size after having been either compressed or extended.

Bodies differ in their degree of elasticity, yet all are more or less elastic. India-rubber, ivory, and whalebone are examples of highly elastic bodies. Putty and clay are examples of those which are only slightly elastic.

If air be compressed, its elasticity tends to restore it to its original bulk; this property has been utilized in making air-beds, air-cushions, and even in forming car-springs. If a spring of steel be bent, its elasticity tends to unbend it; this principle is employed in giving motion to watches, clocks, and the like. If a body be twisted, its elasticity tends to untwist it, as is observed in the tendency of yarn and thread to untwist; this principle, under the name of *torsion*, is used to measure the deflective force of magnetism. If a body be stretched, its elasticity tends to reduce it to its original length, as is shown by stretching a piece of india-rubber, and then allowing it to contract.

We see that the elasticity of a body may be brought into play by four different methods: by *pressure*, by *flexure* or bending, by *torsion* or twisting, and by *tension* or stretching. In whatever way it may be developed, it is the result of molecular displacement. Thus, when air is compressed, the repulsions between the molecules tend to expand it. Again, when a spring is bent, the particles on the outside are drawn asunder, whilst those on the inside are pressed together; the attractions of the former and the repulsions of the latter tend to restore the spring to its original shape.

The most elastic bodies are gases; after them come tempered steel, whalebone, india-rubber, ivory, glass, etc.

Fig. 5 illustrates the method of showing that ivory is elastic,

and at the same time that the cause of its elasticity is molecular displacement. It represents a polished plate of marble, over which is spread a thin layer of oil. If a ball of ivory be let fall upon it from different heights, it will at each time rebound, leaving a circular impression on the plate, which is the larger as the ball falls from a greater height. This experiment shows that the ball is flattened each time by the fall, that the flattening increases as the height increases, and that the repellent action of the compressed molecules causes it to rebound.

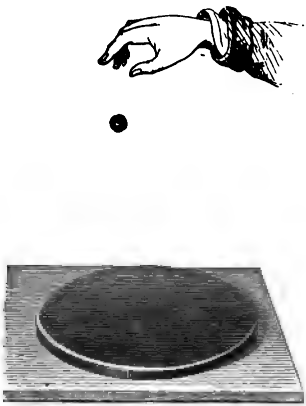

Fig. 5.

The property of elasticity is utilized in the arts in a great variety of ways. When a cork is forced into the mouth of a bottle, its elasticity causes it to expand and fill the neck so as to render it both water and air tight. It is the elasticity of air that causes india-rubber balls, filled with air, to rebound when thrown upon hard substances. It is the elasticity of steel that renders it of use in springs for moving machinery, as well as for easing the motion of carriages over rough roads. It is the elasticity of cords that renders them suitable for musical instruments. It is the elasticity of air that renders it a fit vehicle for transmitting sound.

Summary. —

Physical Agents or Forces.

A Body.

Molecules and Atoms.

Mass and Density.

Three States of Bodies.

General Properties of Bodies.

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" " Liquids.
" " Solids.
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" " Tension.
" " Torsion.
" " Flexure.

SECTION II. — SPECIFIC PROPERTIES OF MATTER.

21. The *specific* or *characteristic properties of matter* depend upon certain forces, which are continually acting between the molecules of bodies. Those which cause the molecules to attract one another are called *Molecular* Forces. They are Cohesion, Adhesion, and Chemical Affinity. These act only at insensible distances.

The ultimate particles, even of solid bodies, do not touch one another, but are kept in place by the combined action of forces of attraction and repulsion. Heat is the repellent force that tends to separate the molecules; although not usually classed as a molecular force, it *here acts* as one, and, like those mentioned, at insensible distances. Chemical affinity belongs to Chemistry, and will not be considered here.

22. **Cohesion and Adhesion.** — COHESION is the force that holds molecules of the same kind together.

ADHESION holds unlike molecules together.

The permanent form of solid bodies depends upon cohesion, which binds the particles together and keeps them in place.

If a solid body be broken or divided in any way, the parts cannot, in general, be made to cohere by simply bringing them together.

The reason is that the molecules are not brought near enough to each other for cohesion to act. In the case of certain bodies, however, the parts may be brought within the range of molecular attraction, by pressure, by partial melting, or by simple contact.

Two pieces of lead with smooth, freshly cut surfaces will cohere strongly if pressed firmly together. Several pieces of iron may be formed into one coherent mass by the process of welding, in which the parts are softened by intense heat, and then hammered together.

If a piece of pure india-rubber be cut in two, and the parts brought together again, they will unite and cohere strongly.

The force of adhesion gives value to mortar, glue, and all kinds of cements.

SOLUTION is due to adhesion. Thus, when sugar dissolves in water, it is because the adhesion between the molecules of sugar and water is stronger than the cohesion between the molecules of sugar. When a liquid tends to spread over the surface of a solid it is said to wet it, as water upon glass. If it gathers in globules it does not wet it, as quicksilver upon glass.

In the first case the force of adhesion between the water and the glass overcomes the force of cohesion which would tend to collect the water in globules. In the second case the formation of the globules shows that the force of cohesion in the mercury is greater than that of adhesion between the glass and the mercury.

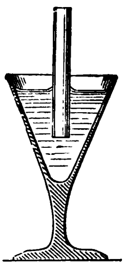


Fig. 6.

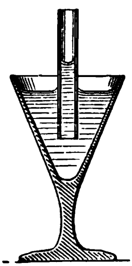


Fig. 7.

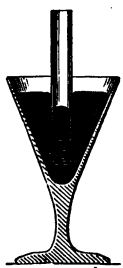


Fig. 8.

23. **Capillarity.** — When a body is plunged into a liquid which is capable of wetting it, as when a glass rod is

plunged into water, it is observed that the liquid is slightly elevated about the body, taking a concave form, as shown in Fig. 6.

If a hollow tube is used instead of a rod, the liquid will also rise in the tube, as shown in Fig. 7. The smaller the bore of the tube, the higher will the liquid rise, and the more concave will be its upper surface. A tube one hundredth of an inch in diameter will support a column of water four inches high.

Instead of a tube two plates of glass brought very near together may be placed in water, and the water will rise in the space between them. The nearer the plates, the higher the liquid will rise. Two plates one hundredth of an inch apart will support a column of water two inches in height. If the plates are in contact at the edges on one side, and slightly separated at the other, as shown in Fig. 9, the water takes the shape of a curve called the hyperbola.

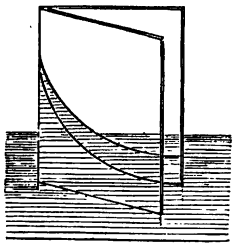


Fig. 9.

When a tube is plunged into a liquid which is not capable of wetting it, as when glass is plunged into quicksilver, the liquid is depressed both on the outside and on the inside, taking a convex surface, as shown in Fig. 8. The smaller the tube, the greater will be the depression, and the more convex will be the upper surface.

24. Applications of Capillarity. — It is in consequence of capillary action that oil is raised through the wicks of lamps, to supply the flame with combustible matter. The fibres of the wicks leave between them a species of capillary tubes, through which the oil rises.

If a piece of sugar have its lower end dipped in water, the water will rise through the capillary interstices of the sugar and fill them. This drives out the air and renders the sugar more soluble than when plunged dry into water, in which case the contained air resists the absorption of water, and retards solution.

If a bar of lead be bent into the form of a siphon, and the short

arm be dipped into a vessel of mercury, the mercury will rise into the lead by capillary action, and flowing over the edge of the vessel will descend along the lower branch and escape from the lower extremity. In this way the vessel may be slowly emptied of the quicksilver.

Many fluids may be drawn over the edges of the containing vessels by a siphon of candle-wicking or other capillary substance.

25. **Absorption** is the penetration into a porous body, of any foreign body, whether solid, liquid, or gaseous.

Carbon, in the form of charcoal, has a great capacity for absorbing gases. If a burning coal be introduced into a bell-glass filled with carbonic acid collected over mercury, the volume of the gas is diminished by being absorbed by the coal. It is found that the charcoal absorbs in this way thirty-five times its own volume of the gas. Charcoal also absorbs other gases in even still greater quantities.

Spongy platinum absorbs hydrogen so rapidly as to heat the platinum red-hot.

In vegetables and animals we have many examples of absorption. The roots of plants absorb from the earth the material necessary to the growth of the stem and branches.

In the animal world, absorption plays an important part in the process of nutrition and growth. Animal tissues also absorb solid substances. For example, workmen engaged in handling lead absorb through the skin and lungs more or less of this substance, which often gives rise to very serious diseases.

When vegetable and animal substances absorb water, they generally augment in volume. This fact explains many phenomena of daily observation.

If a large sheet of paper be moistened, it increases in size, and again contracts when dried. This property is employed by draughtsmen to stretch paper on boards. The paper is moistened, and after being allowed to expand, its edges are glued to a drawing-board; on drying it is stretched, forming a smooth surface for drawing upon. The same property causes the paper to peel from the walls of a room when exposed to moisture.

When a workman would bend a piece of wood, he dries one side and moistens the other. The side which is dried contracts, and the

opposite side expands, so that the piece is curved. It is the absorption of moisture that causes the wood-work of houses, furniture, etc., to swell and shrink with atmospheric changes, and which necessitates their being painted and varnished. Paints and varnishes, by filling the pores, prevent absorption.

26. **Osmose.** — If two liquids of different kinds are separated by a porous or membranous partition, each liquid will begin to pass through the membrane and mix with the other, and after a time there will be a mixture of both liquids on each side of the partition. This movement of the liquids is called osmose. The currents are generally unequal, so that there is an actual gain of substance on one side, and a corresponding loss on the other.

The current that acts to produce an increase on one side is called *endosmose*, and the opposite current is called *exosmose.*

To illustrate this process, let a bladder filled with strong syrup be tied to the end of a glass tube, and the whole placed in a vessel of water, as shown in the figure. The syrup soon becomes diluted by the flowing in of water, and the mixture rises in the tube; at the same time a portion of the syrup flows out and mixes with the water. The flowing in of the water is *endosmose*, and the flowing out of the syrup is *exosmose.* Similar results are obtained by using other liquids.

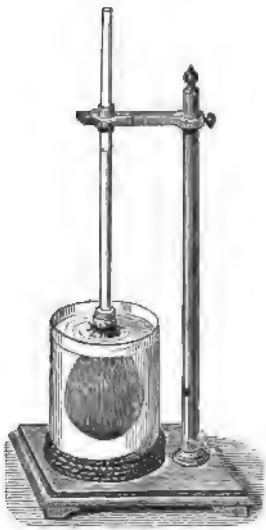


Fig. 10.

The principle of osmose is of very great importance in animal and vegetable physiology. The circulation of fluids through the tissues and vessels of the animal body, the absorption of water by the roots of plants, the circulation of the sap, and many other vital phenomena depend upon this principle.

27. Dialysis.—The practical application of the principle of osmose in separating the constituents of a liquid is called *dialysis.*

Substances which are capable of forming crystals will, when in solution, readily pass through membranes or porous partitions. Pure sugar and various kinds of salts are substances of this kind.

On the other hand, substances which do not crystallize, like gelatine, gum arabic, etc., do not so readily pass through septa. Hence pure crystallizable sugar may, by this process, be separated from the syrup of sorghum, or that of the beet-root, which contains gummy substances that would otherwise prevent crystallization.

28. Tenacity is the resistance which a body offers to rupture when subjected to a force of traction, that is, a force which tends to tear the particles asunder.

The tenacity of a body may be determined in pounds. For this purpose it is wrought into a cylindrical form, having a given cross-section; its upper end is then made fast, and a scale-pan is attached to the lower end; weights are then placed in the pan until rupture takes place. These weights measure the tenacity of the body.

Metals are the most tenacious of bodies, but they differ greatly from each other in this respect. The following table exhibits the weights required to break wires of $\frac{855}{10000}$ of an inch in diameter, formed of the metals indicated:—

Iron	549 lb.
Copper	302 "
Platinum	274 "
Silver	187 "
Gold	150 "
Lead	27 "

It has been shown by theory and confirmed by experiment, that of two cylinders of equal length and containing the same amount of material, one being solid and the other hollow, the latter is the stronger.

This latter principle is also true of cylinders required to support weights; the hollow cylinder is better adapted to resist a crushing force than the solid one of the same weight, and hence it is that columns and pillars for the support of buildings are made hollow. This principle also indicates that the bones and quills of birds, the

stems of grasses and other plants, being hollow, are best adapted to secure a combination of lightness and strength.

The tenacity of metals is greatly increased by drawing them into wire. Hence cables formed of fine iron wire twisted together are much stronger than chains or solid rods of the same weight. Such cables are extensively used for suspension bridges and for many other purposes.

29. **Hardness** is the resistance which a body offers to being scratched or worn by another. Thus, the diamond scratches all other bodies, and is therefore harder than any of them.

For the purpose of determining the relative hardness of minerals, the following scale has been adopted, in which any substance is scratched by those above it in numerical order: —

SCALE OF HARDNESS OF MINERALS.

1. Talc.	6. Feldspar.
2. Gypsum.	7. Quartz.
3. Calc-spar.	8. Topaz.
4. Fluor-spar.	9. Sapphire.
5. Apatite.	10. Diamond.

A body which neither scratches nor is scratched by any given mineral of the table is said to be of the degree of hardness represented by that mineral.

If it scratches one of them, but is itself scratched by the next one above it in the scale, the degree of hardness is between the two with which it is compared. Thus, a piece of the mineral *scapolite* can be scratched by feldspar, but will scratch a piece of apatite; hence its hardness is between 5 and 6 of the scale.

Hardness must not be confounded with resistance to shocks or compression. Glass, diamond, and rock-crystal are much harder than iron, brass, and the like, and yet they are less capable of resisting shocks and forces of compression; they are more *brittle.*

An alloy or mixture of metals is generally harder than the separate metals of which it is composed. Thus, gold and silver are soft metals, and, in order to make them hard enough for coins and jewelry, they are alloyed with a small portion of copper. In order to render block-tin hard enough for the manufacture of domestic utensils, it is alloyed with a small quantity of lead.

The property of hardness is utilized in the arts. To polish bodies, powders of emery, tripoli, and other hard minerals, are used. Diamond being the hardest of all bodies, it can be polished only by means of its own powder. Diamond-dust is the most efficient of the polishing substances.

30. Ductility is the property of being drawn out into wires by forces of extension.

Wax, clay, and the like, are so tenacious that they can easily be flattened by forces of compression, and readily wrought between the fingers. Such bodies are plastic. Glass, resins, and the like become tenacious only when heated. Glass at high temperatures is so highly ductile that it may be spun into fine threads and woven into fabrics. Many of the metals, as iron, gold, silver, and copper, are ductile at ordinary temperatures, and are capable of being drawn out into fine wires by means of wire-drawing machines.

The following metals are arranged in the order of their ductility: *platinum, silver, iron, copper, gold, zinc, tin, lead.*

31. Malleability is the property of being flattened or rolled out into sheets, by forces of compression.

This property often augments with the temperature; every one knows that iron is more easily forged when hot than when cold. Gold is highly malleable at ordinary temperatures. Gold is reduced to thin sheets by being rolled out into plates by a machine; these plates are cut up into small squares, and again extended by hammering until they become extremely thin. They are then cut up again into squares, and hammered between membranes, called gold-beater's skins. By this process gold may be wrought into leaves so thin that it would take 282,000, placed one upon another, to make an inch in thickness. These leaves are employed in gilding metals, woods, paper, and the like. Silver and copper are wrought in the same manner as gold.

The most malleable of the metals are not necessarily the most ductile. Lead and tin, for example, have very little ductility, but are malleable to a very high degree. Zinc is only slightly malleable when cold, but is easily rolled out into sheets at a temperature of 300° or 400° F.

The malleability of the metals is not the same when hammered as when rolled. The following is the order of malleability under the

hammer: *Lead, tin, gold, zinc, silver, copper, platinum, iron.* Under the rolling-mill the order is as follows: *Gold, silver, copper, tin, lead, zinc, platinum, iron.*

Summary. —

SPECIFIC PROPERTIES OF MATTER.

Molecular Forces.

Cohesion. Experiments.

Adhesion. Glue and Cements.
Solution.

Capillarity in Tubes.
" between Plates.
" Applications of.
Absorption.
Osmose.
Dialysis.

Tenacity, Measure of.
" Table of.
" of Metals: how increased.

Hardness.
Scale of Hardness.
Hardness of Alloys.
Polishing Powders.

Ductility.
Metals most ductile.

Malleability.
Effect of Heat.
Gold-beating.
Malleability under the Hammer.
" " " Rolling-mill.

CHAPTER II.

MECHANICAL PRINCIPLES.

SECTION I. — MOTION AND FORCE.

32. MECHANICS is that branch of Physics which treats of the laws of rest and motion. It also treats of the action of forces upon bodies.

33. **Rest and Motion.** — A body is at REST when it retains its position in space. It is in MOTION when it continually changes its position in space.

A body is at rest with respect to surrounding bodies, when it retains the same relative position with respect to them, and it is in motion with respect to surrounding objects when it continually changes its relative position with respect to them. These states of rest and motion are called ***Relative Rest*** and ***Relative Motion***, to distinguish them from ***Absolute Rest*** and ***Absolute Motion***.

When a body remains fixed on the deck of a moving vessel or boat, it is at rest with respect to the parts of the vessel, although it partakes with them in the common motion of the vessel. When a man walks about the deck of a vessel, he is in motion with respect to the parts of the vessel, but he may be at rest with respect to objects on shore; this will be the case when he travels as fast as the vessel sails, but in an opposite direction. In consequence of the earth's motion around its axis and about the sun, together with the motion of the whole solar system through space, it is not likely that any part of our system is in a state of absolute rest at any time.

34. **Uniform Motion** is that in which a body passes over equal spaces in equal times. Thus, every point on the sur-

face of the earth is, by its revolution, carried around the axis with a uniform motion.

In this kind of motion the space passed over in one second of time is called the *velocity*. Thus, if a train of cars travel uniformly at the rate of 20 miles per hour, its velocity is 29.3 feet. Instead of taking a second as the unit of time, we might adopt a minute or an hour. In the same case as before we might say that the velocity of the train is one third of a mile per minute, or twenty miles per hour.

35. Varied Motion — Accelerated and Retarded Motion. — VARIED MOTION is that in which a body passes over unequal spaces in equal times. If the spaces passed over in equal times go on increasing, the motion is *accelerated;* such is the motion of a train of cars when starting, or that of a body falling towards the surface of the earth. If the spaces passed over go on decreasing, the motion is *retarded;* such is the motion of a train of cars when coming to rest, or that of a body thrown vertically upwards.

When the spaces passed over in equal times are continually increased or decreased by the same quantity, the motion is *uniformly accelerated*, or *uniformly retarded.* The motion of a body falling in a vacuum is *uniformly accelerated;* that of a body shot vertically upwards in a vacuum is *uniformly retarded.*

36. Laws of Motion. — The principles of Mechanics are all based upon three propositions, known as Newton's Laws of Motion. The following is —

37. Newton's First Law. — *Every body continues in a state of rest or of uniform motion in a straight line unless it is acted upon by some external force.* This is called the Law of Inertia because it depends upon that property of matter.

That a body cannot set itself in motion, and that bodies set in motion tend to move in straight lines, are facts that are verified by every-day observation.

It is not so obvious that a state of motion is as *natural* to a body

as a state of rest, but a little consideration of certain facts will show that this is also true.

In the first place, it may be observed that whenever a moving body is brought to rest it is in consequence of resistance of some kind; and in proportion as the resistance is removed the motion is longer continued. Thus, a ball rolled along the ground will soon be stopped; if rolled with the same force upon a smooth floor it will go much farther, and still farther if rolled along a smooth sheet of ice. We cannot *prove* that it would continue to move on uniformly forever if there were no resistance, but we may *infer* that it would from the fact that the less the resistance the more uniform is the rate of motion, and the longer it continues to move.

38. Newton's Second Law. — The following is Newton's Second Law of Motion: —

Motion, or a change of motion, is proportional to the force impressed, and is in the direction of the line in which that force acts.

In order to understand the action of a force, three things must be known: its *point of application*, its *direction*, and its *intensity*.

The *point of application* is the point where the force exerts its action.

The *direction* of a force is the line along which it acts.

The *intensity* of a force is the energy with which it acts.

The intensity of a force is measured in units of weight; thus, a force of fifty pounds is the force required to sustain a weight of fifty pounds. The intensity of a force may be represented by a distance laid off on its line of direction. Assuming some unit of length, say one tenth of an inch, to represent one pound, this is set off as many times as the force contains pounds.

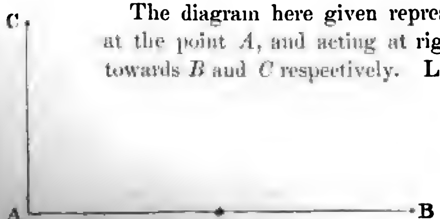


Fig. 11.

The diagram here given represents two forces applied at the point A, and acting at right angles to each other towards B and C respectively. Let the force which acts from A towards B equal twenty pounds, and that which acts from A to C equal ten pounds.

Adopting the scale

of one tenth of an inch to the pound, the line $A\ B$ must be two inches, and the line $A\ C$ one inch in length, to represent correctly the relative intensity of the two forces.

39. Simple and Compound Motion. — Simple motion is produced by the action of a single force. Compound motion is produced by the simultaneous action of two or more forces. When a body is acted upon by a single force it will move in a straight line in the direction of that force.

If a body is acted upon by two or more forces in the same direction, it will move with an intensity represented by the *sum* of the forces. If acted upon by two forces in opposite directions, it will move with an intensity represented by the *difference* of the forces, and in the direction of the greater force.

If two or more forces act upon a body, neither in the same nor in opposite directions, but in lines forming some angle with each other, it will not, in general, move in the direction of any one of them, but will move in some intermediate direction as if impelled by a single force.

In any of these cases the single force which results from the combination of two or several forces is called their *Resultant.*

The separate forces are called *Components* of the resultant.

40. Parallelogram of Forces. — In the diagram let $A\ B$ and $A\ D$ represent two forces acting at A, their resultant will be represented by $A\ C$. That is, *if two forces are represented in direction and intensity by the adjacent sides of a parallelogram, their resultant will be represented in direction and intensity by that diagonal which passes through their point of intersection.*

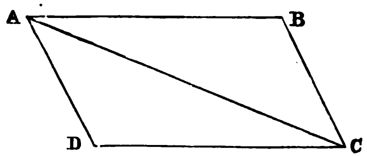


Fig. 12.

This principle is called the *Parallelogram of Forces.*

The operation of finding the resultant when the compo-

nents are given is called *Composition of Forces;* the reverse operation is called *Resolution of Forces.*

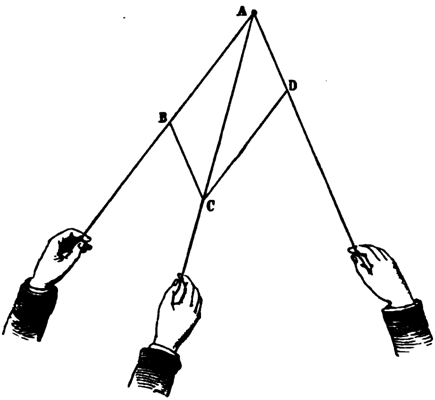


Fig. 13.

When two forces are applied at the same point, as shown in Fig. 13, we lay off distances AB and AD to represent the forces, and having completed the parallelogram, we draw its diagonal AC; this will be their resultant. If the resultant AC is known, and the directions of its components are given, we draw through C the lines CD and CB parallel to their directions; then will the intercepted lines AD and AB be components of the force AC.

41. Example of Composition of Forces.—A bird, in flying, strikes the air with both wings, and the latter offers a

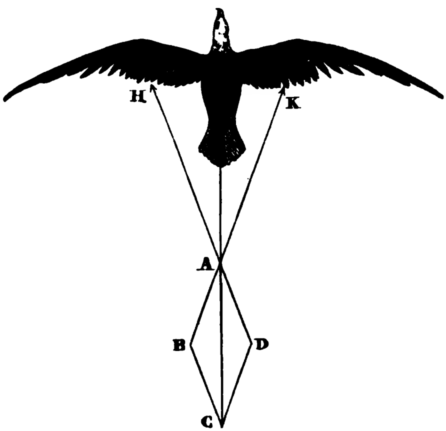


Fig. 14.

resistance which propels him forward. Let *A K* and *A H*, in Fig. 14, represent these resistances. Draw *A B* and *A D* equal to each other, and complete the parallelogram *A C*; draw also the diagonal *A C*. Then will *A C* represent the resultant of the two forces, and the bird will move exactly as though impelled by the single force *C A*.

42. **Example of Resolution of Forces.** — When a sail-boat is propelled by a breeze acting on the quarter in the direction ***v a*** (Fig. 15) we may, by the rule in Art. 40, resolve the intensity of the wind into two components, one, ***c a***, in the direction of the keel, and the other, ***a b***,

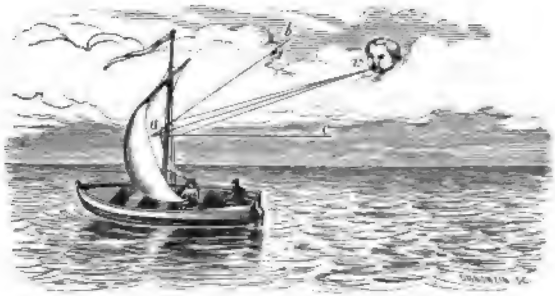


Fig. 15.

at right angles to it. The first component alone is effective in giving a forward motion to the boat, whilst the second is partly destroyed by the resistance which the water offers to the keel, and partly employed in giving a lateral motion to the boat. This lateral motion is called *leeway*.

43. **Resultant of Parallel Forces.** — When two forces act in the same direction, as when two horses pull at the ends of a whiffletree to draw a wagon, *their resultant is equal to the sum of the forces*. When they act in a contrary direction, as in the case of a steamboat ascending a river, where the force of the engine acts to propel the boat forward while the current acts to retard its progress, *their resultant is equal to the difference of the forces*.

44. Composition of more than Two Forces.—If more than two forces act upon the same point, the resultant of any two may be combined with a third, this resultant with a fourth, and so on. The last resultant will represent the combined action of all the given forces.

Summary.—

MECHANICAL PRINCIPLES.
- *Rest and Motion.*
  - Absolute.
  - Relative.
  - Uniform Motion.
    - Velocity.
  - Accelerated Motion.
  - Retarded Motion.
- *Laws of Motion.*
  - Newton's First Law.
  - The Law of Inertia.
    - Illustrations.
  - Newton's Second Law.
    - Point of Applications of Force.
    - Intensity of Force.
    - Direction of Force.
    - Measure of Intensity.
- *Simple and Compound Motion.*
  - Components.
  - Resultant.
  - Parallelogram of Forces.
  - Composition of Forces.—Example.
  - Resolution of Forces.—Example.
  - Resultant of Parallel Forces.
  - Composition of more than Two Forces.

45. Momentum.—*The Momentum of a body is its quantity of motion.*

It may also be defined as the measure of the force with which a body moves.

If the same amount of force is employed in putting in motion bodies of different weight, it is evident that the

greater the weight of the body the less will be the velocity imparted. A force that will move a body of one pound weight through a space of ten feet in a second, will move a body weighing two pounds through only half the space in the same time.

It is evident, however, that the *quantity of motion* will be the same in each case; for if we suppose the larger body to be divided into two equal parts which move side by side, the sum of the distances described will be equal to the distance through which the body weighing one pound will move in the same time.

Of two equal masses that which moves with the greater velocity has the greater momentum; of two unequal masses having the same velocity, the heavier mass has the greater momentum.

Momentum depends, therefore, upon weight and velocity, and may be estimated by the following rule: —

Multiply the weight of the body by its velocity.

Example. What is the momentum of a ten-pound ball moving at the rate of 500 feet per second?

$$10 \times 500 = 5000, \quad \text{Ans.}$$

It will be seen that according to this rule bodies of immense weight may move with great force, though the rate of motion may be very slow. For example, an iceberg, whose motion is hardly perceptible, may exert a tremendous crushing force upon any object with which it comes in contact.

A large vessel moving slowly up to a wharf has so great momentum that unless some precaution be used there is danger of damage both to the vessel and the wharf. To prevent this it is customary to place a coil of rope or some other elastic and yielding substance between the sides of the vessel and the wharf.

On the other hand, a body of very small weight may move with velocity so great as to exert a greater force than a large body moving slowly. Thus, a bullet fired from a gun has a greater momentum than a stone many times heavier thrown from the hand.

46. Collision of Bodies. — The term momentum, as now generally used, refers only to the force expended in the

motion of the moving body itself, and to its power of communicating motion to other bodies. This does not represent the whole effect which a moving body produces upon another body upon which it strikes.

If a bullet is fired into a wooden block, which is suspended by a cord so that it is free to move, the momentum of the bullet is transferred to the block, and the momentum of the block after impact is equal to that of the bullet before it strikes. But the force of the bullet is not all expended in setting the block in motion; it *penetrates* the block to a greater or less extent according to its velocity.

If the whole of the force with which a body moves is expended upon an immovable obstacle, it is found that the effect produced is proportional to the *square of the velocity.*

Thus, suppose a bullet to be fired into an immovable block, with a force that causes it to penetrate to the depth of one inch; if it strike the block with *twice* that velocity it will sink into it four inches; or with three times the velocity, to the depth of nine inches.

47. Striking Force. — The power of a moving body to overcome resistance is called its *striking or living force* (*vis viva*), and is proportional to the *square of the velocity*.

It appears, then, that two bodies may have the same momentum and at the same time differ greatly in their striking force.

For example, an iron ball weighing 50 pounds and moving 100 feet per second, and a second ball weighing 5 pounds and moving 1,000 feet per second, will have the same momentum (= 5,000). The striking force of the first will equal $50 \times 100^2 = 500{,}000$. That of the second will be equal to $5 \times 1000^2 = 5{,}000{,}000$. Hence, if both were thrown against a bank of earth, the second would penetrate ten times as far as the first. This subject will be further treated of under the head of Energy.

48. Action and Reaction — Newton's Third Law. — We use the term *Action* to denote the power which a moving body has to impart motion or force to another body, and the term *Reaction*, to express the power which the body acted upon has to deprive the acting body of its motion or force, or to impart motion in an opposite direction.

The following is Newton's *Third Law*, which expresses the relation of these two forms of force.

Action and reaction are always equal, and are in opposite directions.

49. Reaction in Non-Elastic Bodies.—Let two balls of clay or some other non-elastic substance be suspended by cords of equal length, so as to hang side by side in front of a graduated arc, as shown in Fig. 16. If one be drawn aside and let fall so as to strike the other, both will move forward, but not so far as the first would have moved alone. If the balls are of equal mass, the two will move together through half the distance that the first alone would have traversed. The first ball loses half its momentum by the *reaction* of the second, and the second gains precisely the same amount of momentum by the *action* of the first. The momentum of the combination therefore remains the same after impact as before.

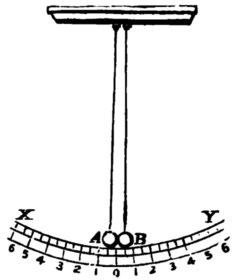


Fig. 16.

50. Reaction in Elastic Bodies.—If two equal balls of some elastic substance, as ivory, be similarly placed, and the same experiment repeated, the first ball will give the whole of its motion to the second and remain motionless, while the second ball will swing as far as the first would have gone had it met no resistance. In this case, also, action and reaction are equal; for the same amount of force required to stop the first ball suffices to give an equal motion to the second.

The same principle may be illustrated by using several elastic balls of equal weight, as shown in Fig. 17.

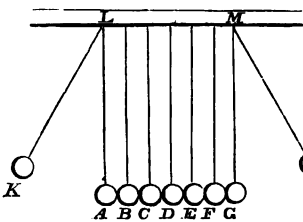


Fig. 17.

Let the ball *H* be drawn out a certain distance and let fall upon *G*, the next in order; it will then communicate its motion

to *G* and receive a reaction from it which will destroy its own motion.

But the ball *G* cannot move without communicating the motion it received from *H* to *F*, and receiving from *F* a reaction which will stop its motion. In like manner the motion and reaction are received by every one of the balls *E*, *D*, *C*, *B*, *A*, until the last ball, *K*, is reached; but there being no ball beyond *K* to act upon it, *K* will fly off as far from *A* as *H* was drawn apart from *G*.

These results would be strictly as stated if the balls were perfectly elastic. In practice it will be found that the last ball will not move quite so far as the theory requires, while the whole system will be slightly thrown forward by the force of the first ball.

A few familiar and interesting illustrations of this law may serve to call the attention of the student to the large number of examples he meets with in his every-day life.

The flight of birds, the onward motion of the steamboat, the rebound of the hammer from the anvil, the recoil of a gun, the ascent of a rocket, are common examples of the law. When we strike the table with the hand, it is the reaction of the table that hurts the hand; so, when we spring from the ground, the earth is really pushed away from us. The motion is not seen, however, because it is diffused through so large a mass.

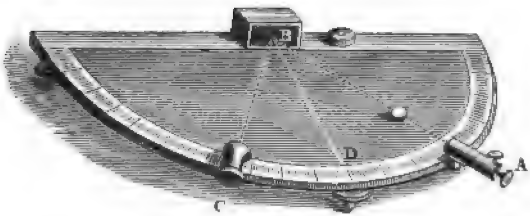


Fig. 18.

51. Reflected Motion. — When an elastic body is thrown against a hard, smooth surface reaction causes it to rebound. If it be thrown in a direction perpendicular to the surface, it will rebound in the same direction; if thrown obliquely, it will rebound obliquely in an opposite direction. The direction in which the body approaches the reflecting surface is its *Line of Incidence*, and that in which it rebounds the *Line*

of Reflection. The angle included between the line of incidence and a perpendicular to the surface is called the *Angle of Incidence.* The angle included between the line of reflection and the perpendicular is called the *Angle of Reflection.*

The Angle of Reflection is equal to the Angle of Incidence. This is the *Law of Reflected Motion.*

In the illustration given in Fig. 18, a ball shot from *A* will be reflected at *B* back to *C*, making the angle *C B D* equal to *A B D*. The law here given applies not only to the motion of solid bodies, but to all forces which act in straight lines and are capable of reflection. It is especially important in its application to the laws of Heat and Light.

52. Centrifugal and Centripetal Forces. — The Centrifugal Force, so called, is not properly a force, but is simply a manifestation of inertia. It is the resistance which a moving body offers to a force which tends to turn it from its course.

In consequence of its inertia, a body always tends to move in a straight line, and if we see it move in a curved line it is because some force is acting to turn it from its path. This deflecting force has been called the Centripetal Force, because in circular motion it tends to draw the moving body towards the centre of the circle.

If a ball is whirled about the hand, being retained by a string, it has a continual tendency to fly off, which tendency is resisted by the strength of the string; the tendency to fly off is due to the centrifugal force, and that which resists this tendency is the centripetal force.

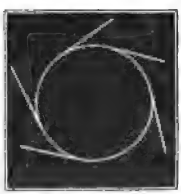


Fig. 19.

The curved path in which a body moves may be regarded as made up of short straight lines; and if at any instant the centripetal force is destroyed, the body will continue to move along that line on which it was situated, that is, its new path will be tangent to its old one.

In the example given above, if the string is broken in whirling, the centripetal force no longer acts, and the ball in consequence of its inertia moves on in a straight line which is tangent to the circle, as shown in Fig. 19.

The existence of the centrifugal force may be shown experimentally by the apparatus represented in Fig. 20. In consists of a bar, *A B*, having its ends bent up so as to hold a wire which is stretched between them. On this wire two ivory balls are strung so as to slide along it, and the whole bar is made to turn about an axis at right angles to it by means of a crank and two bevelled wheels When the bar is made to revolve about the axis, the balls, acted upon by the centrifugal force, are thrown against the end of the bar with an energy which becomes greater as the motion of revolution becomes more rapid.

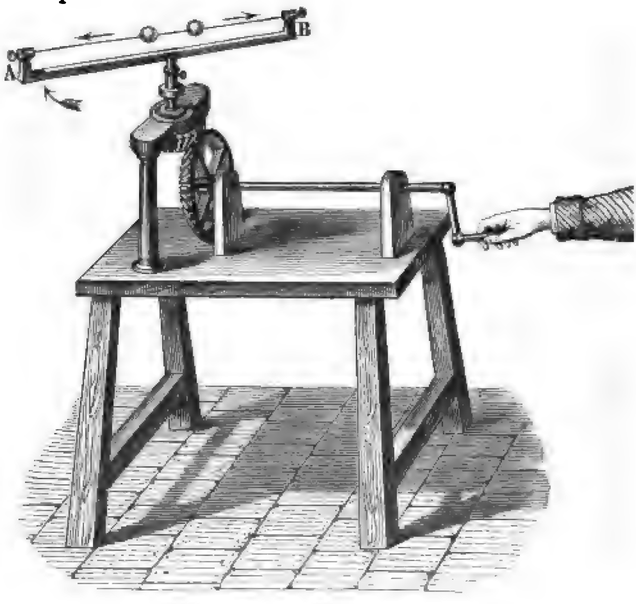


Fig. 20.

53. Some Effects of the Centrifugal Force. — When a train of cars turns round a curve in the road, the centrifugal force tends to throw the train off the track, a tendency which is resisted by raising the outer rail and by making the wheels conical.

It is in consequence of the centrifugal force, that the mud adhering to the tire of a carriage-wheel is thrown off in all directions.

In the circus, where horses are made to travel rapidly around in a

curved path, the centrifugal force tends to overturn them outwards, which tendency is partly overcome by making the outside of the track higher than the inside, and partly by both horse and rider inclining inwards, so as to make the resultant of their weight and the centrifugal force perpendicular to the path.

When a sponge filled with water and held by a string is whirled rapidly around, the centrifugal force throws off the water and leaves the sponge dry. This principle has been used for drying clothes in the laundry.

A very remarkable effect of the centrifugal force is the flattening of our earth at the poles. The earth turns on its axis every twenty-four hours, which rotation gives rise to a centrifugal force at every point of its surface. At the equator the centrifugal force is greatest, because the velocity is there the greatest, and from the equator it grows feebler towards each pole, where it is zero. The centrifugal force at every point is perpendicular to the axis, and may be resolved into two components, one directed outwards from the centre, and the other perpendicular to this. The former component lessens the weight of bodies, and the latter acts to heap the particles up towards the equator. It has been found that the earth is a spheroid, flattened at the poles. The polar diameter is about twenty-six miles shorter than the equatorial diameter. Observations upon the heavenly bodies show that other planets are in like manner flattened at their poles.

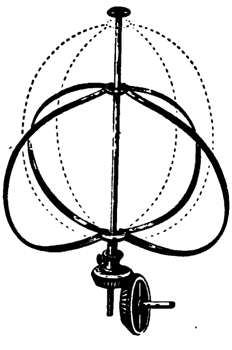


Fig. 21.

The manner in which the centrifugal force acts to flatten a sphere is shown experimentally by an apparatus represented in Fig. 21. This apparatus consists of a vertical rod to which a motion of rotation may be imparted, as shown in Fig. 20. At the lower part of this rod four strips of brass are firmly fastened and bent into circles, as shown by the dotted lines; their upper ends are fastened to a ring which is free to slide up and down the rod. When the axis is made to revolve rapidly, the centrifugal force causes the ring to slide down the rod, the hoops become more curved, as shown in the figure, and the whole assumes the appearance of a flattened sphere.

There is a tendency in all bodies to revolve about their shortest axis, and from this fact we infer that the earth will always maintain its present rotation about its shortest or polar diameter.

This principle can be verified in various ways. If a cylinder be suspended by a string which is attached a little to one side of the longer axis, and then be made to revolve rapidly by twisting the string, the cylinder will change its position and revolve about an axis perpendicular to its length; that is, it rotates about its shorter axis.

This same tendency is observed if, instead of a cylinder, we use a cone, chair, or ring.

54. The Gyroscope (Fig. 22) is an instrument to illustrate the composition of rotary motions. It consists of a disk, *T*, revolving in a ring, *C*.

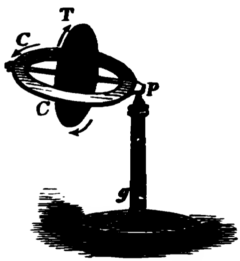


Fig. 22.

The disk is made to rotate by winding a cord about the axis and then suddenly pulling it off. While in rapid rotation the end of the axis is placed upon the pivot, *P*; instead of falling, the whole begins to revolve rapidly in a horizontal plane about the vertical support, *P g*. If the ring, *C*, be depressed while the disk is in motion it will rise again and revolve in the same plane as before.

This motion is the resultant between the force of gravity and the rotary motion of the wheel.

Summary.—

Momentum.
- Quantity of Motion.
- Relation to Velocity and Weight.
- Rule for finding Momentum.
  - Examples.

Collision of Bodies.
- Striking Force (*Vis viva*).
- Rule for Striking Force.
  - Examples.

Action and Reaction.
Newton's Third Law.
Reaction in Non-Elastic Bodies.
" " Elastic Bodies.
Familiar Illustrations.

Reflected Motion.
Lines of Incidence and Reflection.
Angles of Incidence and Reflection.
Law of Reflected Motion.
Illustration.

Centrifugal and Centripetal Forces.
Centrifugal Force or Manifestation of Inertia.
Curved Path of a Moving Body made up of straight lines.
Illustration.
Effects of Centrifugal Force.
Spheroidal Shape of the Earth.
Experiments.

The Gyroscope.

SECTION II. — PRINCIPLES DEPENDENT ON THE ATTRACTION OF GRAVITATION.

55. **Universal Gravitation.** — The earth exerts a force of attraction upon all bodies near it, tending to draw them towards its centre. This force, called the *Force of Gravity*, when unresisted, imparts motion, and the body is said to fall; when resisted, it gives rise to pressure, which is called *Weight*.

Newton showed that the force of gravity, as exhibited at the earth's surface, is only a particular case of a general attraction extending throughout the universe, and continually tending to draw bodies together. This general attraction he called *Universal Gravitation.* It is mutually exerted between any two bodies whatever, and it is by virtue of it that the heavenly bodies are retained in their orbits.

The law of Gravitation discovered by NEWTON, may be expressed as follows: *Any two bodies exert upon each other a mutual attraction, which varies directly as their masses, and inversely as the square of their distance apart.*

The first part of the law can be best explained by examples. When a stone falls to the earth there is a mutual attraction between the earth and the stone, but the mass of the former is so much greater than that of the latter that no perceptible effect is produced upon it by the stone. The attractive influence of the earth is not confined to objects in its immediate vicinity, but is felt also by the sun, moon, and planets, and these in turn attract the earth. By the superior attraction of the earth the moon is compelled to be its constant attendant in its ceaseless journey through space. The sun by virtue of its greater mass keeps the planets in their orbits and preserves the harmony of the solar system. If a leaden ball be suspended near the precipitous side of a mountain, there will be noticed a leaning of the ball from the vertical towards the mountain.

When we say that any two bodies exert upon each other a mutual attraction that varies directly as their masses, we mean simply that if one contains twice as much mass as the other its power of attraction is twice as great as the other; if its mass is one half as great as that of the other, its power of attraction will also be one half as great.

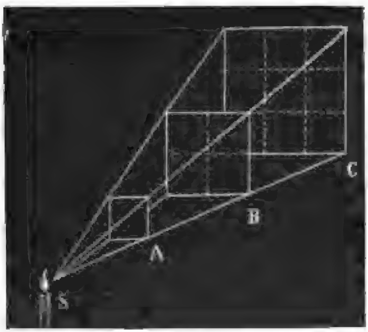


Fig. 23.

The second part of the law, that the attraction of the bodies varies inversely as the square of their distance apart, may be further illustrated by Fig. 23. Let S be the centre of attraction, and the diverging lines the lines of the attractive force. At the distance A from the point S the four lines of attraction enclose the single square A, and hence it receives the full force of the attraction. The square B is four times as large as A, but receives only the same amount of attraction; that is, the attraction

is spread over four times as much space, so that a portion of *B* equal in size to *A* would only be attracted one fourth as much.

It is plain, then, that as the distance from *S* increases the attraction decreases, and as the distance decreases the attraction increases, showing an *inverse* ratio. We also see that while the attraction of one of *B*'s squares is *four* times less than *A*'s, it is only *twice* as far from *S*; hence, to ascertain the diminution of attraction at *B*, we must square its distance from *S* compared with *A*'s distance. *C* is nine times as large as *A* and three times as far from *S*; the attraction of one of its squares will be one ninth of *A*'s.

Since all bodies attract one another we should naturally suppose that any two bodies on the earth's surface would come together, as two books placed upon a table; but the superior attraction of the earth binds them to the table, and this neutralizes their mutual attraction.

56. Effect of Gravitation on the Planets.—It is by the influence of gravitation that the planets are retained in their orbits. Their motion is the same as if they had been projected into space with an impulse, and then continually drawn from the right lines along which inertia tends to carry them by the attraction of the sun. The planets also attract the sun, but their masses being exceedingly small in comparison with that of the sun, their effects in disturbing its position are very small. The orbits of the planets are ellipses, differing but little from circles.

57. The Force of Gravity is that force of attraction which the earth exerts upon all bodies, tending to draw them towards its centre.

As has been stated, it is only a particular case of Universal Gravitation. It is, therefore, subject to the same law, that is, *it varies directly as the mass of the body acted upon, and inversely as the square of its distance from the centre of the earth.*

The shape of the earth has been shown by careful measurement to be that of a spheroid, that is, of a sphere slightly flattened at the

poles. The mean radius is a little less than 4,000 miles. On account of the flattening of the earth at the poles, different points are at slightly different distances from the centre, and consequently the force of gravity varies slightly at different places on the surface. For ordinary purposes, however, we may regard the earth as a perfect sphere, and the force of gravity as constant all over its surface.

58. Vertical and Horizontal Lines. — A VERTICAL LINE is a line along which a body falls freely. All vertical lines are directed towards the centre of the earth, but for places near together they may be regarded as parallel.

In Fig. 24, the lines *a o* and *b o* are vertical, but if they are not far apart, their convergence is so small that they may be taken as parallel. If, however, their distance apart is considerable, they cannot

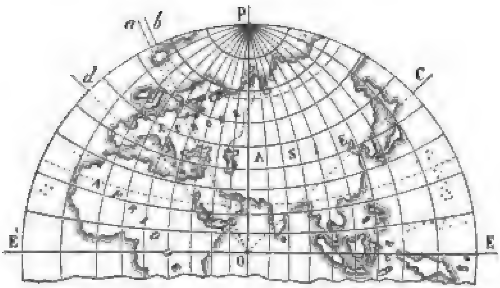


Fig. 24.

be regarded as parallel. A man standing erect has his body in a vertical, and it may happen that two persons on opposite sides of the globe, as at E and E', may both stand erect, and yet their heads be turned in exactly opposite directions, their feet being turned towards each other. Points where this may happen are said to be *antipodes.*

A HORIZONTAL LINE, or PLANE, at any place is one which is perpendicular to a vertical line at that place. The surface of still water is horizontal, or *level.* For small areas this surface may be regarded as a plane, but when a large surface is considered, as the ocean, it must be regarded as curved, conforming to the general outline of the earth's surface.

Upon the principle of verticals and horizontals all of our instruments for levelling and making astronomical observations are constructed.

59. Weight.—The WEIGHT of a body is due to the force of gravity, acting upon all its particles, but it must not be confounded with the force of gravity. Weight is only the effect of gravity when resisted; when gravity is unresisted it produces quite another effect, that is, motion.

At the same place the weights of bodies are proportional to their masses, or the quantities of matter which they contain. We shall see hereafter that the weight of bodies may be determined by means of the balance; the force of gravity is determined by the velocity which it can impart to a body in a certain time, as will be shown more fully hereafter.

60. Centre of Gravity.—The CENTRE OF GRAVITY of a body is that point through which the direction of its weight always passes.

We have seen that the weight of a body is the resultant of the action of gravity upon all of its particles. Now, whatever may be the form of a body, or whatever its position, the direction of its weight always passes through a single point. This point is the *centre of gravity.* Hence, in calculations, the weight of a body may be considered as concentrated in the centre of gravity.

The vertical line which passes through the centre of gravity is called *the line of direction.*

In the case of solids of regular figure and uniform density, the centre of gravity is at the centre of the figure. Thus the centre of gravity of a sphere, a cube, or a regular octahedron, is in each case at the centre. In a cylinder it is at the centre of the axis; in a parallelopipedon, at the intersection of its diagonals; in a pyramid, on its axis at one fourth of its length from the base.

In plates or sheets of uniform thickness and density, the centre of gravity is at the centre of the surface, or rather at the middle of the short line which joins the centres of the opposite surfaces.

When the surface is of irregular outline the position of the centre of gravity may be found in the following way: —

Suspend the body by any part of its edge so that it can move freely, and, by means of a plumb-line, mark on it a vertical line from the point of suspension; again suspend it from some other point of the edge and mark the vertical line; the point where these lines intersect will show the centre of gravity.

By a similar method the position of the centre of gravity in any solid body may be determined; for it will always be found at the intersection of any two *lines of direction.*

In some cases the centre of gravity is not within the substance of the body itself, as, for example, in a ring, a box, or a cask; yet its position may be determined in precisely the same way.

Fig. 25.

Fig. 26.

61. Equilibrium of Heavy Bodies.—The centre of gravity being the point at which the weight is applied, it follows that, if this point is held fast by any support whatever, the effect of the weight is completely counteracted, and the body will be in a state of equilibrium.

If a body has but a single point of support, it can be in equilibrium only when its centre of gravity lies somewhere on a vertical through that point.

If a body has but two points of support, it can be in equilibrium only when its centre of gravity lies in a vertical drawn through some point of the line joining these two points. An example is shown in Fig. 25, which represents a man standing on stilts. To be in equilibrium, his centre of gravity must be exactly over the line joining the feet of his stilts.

If a body has three supports not in a straight line, it will be in equilibrium when the centre of gravity lies on a vertical drawn through any point of the triangle formed by joining these points. An example is shown in Fig. 26, which represents a three-legged table. The centre of gravity being at g, the table will be in equilibrium so long as the vertical through that point pierces the triangle formed by uniting the feet of the table.

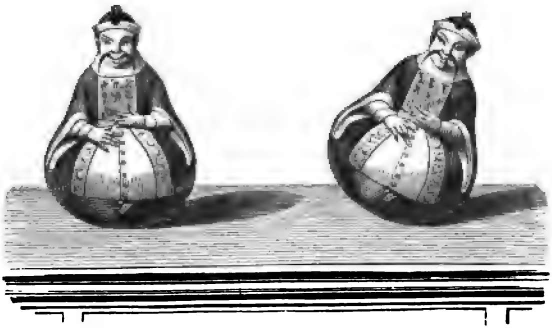


Fig. 27. Fig. 28.

62. Different Kinds of Equilibrium. — When bodies are acted upon by the force of gravity alone, and have one or more points of support, three kinds of equilibrium may exist: *Stable*, *Unstable*, and *Neutral Equilibrium*.

1. *Stable Equilibrium.* — A body is in *stable equilibrium* when, on being slightly disturbed from its state of rest, it tends of itself to return to that state.

This will be the case when the centre of gravity is lower in its position of rest than it is in any of the neighboring po-

sitions, for in this case the weight of the body acting at the centre of gravity tends to keep it in the lowest position. If slightly disturbed from the lowest position, the weight will act to draw it back, and so establish the equilibrium.

We have an example of stable equilibrium represented in Figs. 27 and 28, which represent images often met with in the toy-shops. If the image be inclined to one side, as shown in Fig. 28, it will by its own weight right itself, and take the position shown in Fig. 27. These figures are hollow and light, and are ballasted with lead at their lower part so as to throw the centre of gravity very low. The result is, that when the figure is inclined, the centre of gravity is raised, and the weight acts to restore it. The figure settles in its primitive state of rest only after several oscillations, which are due to the inertia of the body. The explanation of this oscillation is the same as that given for the oscillation of the pendulum.

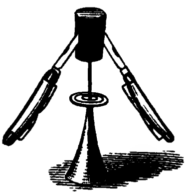


Fig. 29.

When the centre of gravity is considerably below the point of support, a body may be in stable equilibrium even when the base is very narrow. Thus a cork with two pocket-knives sticking in it may rest upon the point of a needle and be in stable equilibrium, as shown in the figure. In this case the heavy handles of the knives bring the centre of gravity below the point of support.

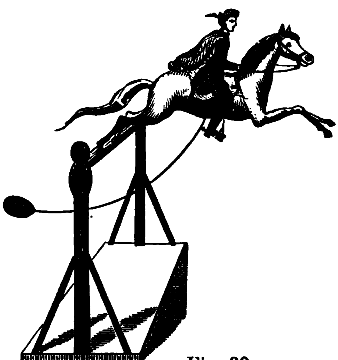


Fig. 30.

In the case of the toy shown in Fig. 30, the heavy ball attached to the figure brings the centre of gravity of the whole below the points of support. It is therefore another example of stable equilibrium.

2. *Unstable Equilibrium.*—A body is in *unstable equilibrium* when, on being slightly disturbed from its state of rest, it does not tend to return to that state, but continues to depart from it more and more.

This will be the case when the centre of gravity is higher in its position of rest than in any of the neighboring positions. When the body is slightly disturbed, the weight acts not only to prevent its return, but also to cause it to descend still lower.

3. *Neutral Equilibrium.* — A body is in *neutral equilibrium* when, on being slightly disturbed, it has no tendency either to return to its former position or to depart farther from it.

This will be the case when the centre of gravity is at the same height when at rest as in any other position; for example, in a ball resting upon a horizontal table.

Examples of the three kinds of equilibrium are given in Fig. **31**. The cone *A* is in stable equilibrium, because its centre of gravity is at its lowest possible position. The cone *B* is in unstable equilibrium, for though it may possibly be balanced on its apex, the slightest movement will throw the line of direction beyond the base and the cone will fall. The cone *C* is in neutral equilibrium, because, if it is rolled around, the centre of gravity will not be raised or lowered.

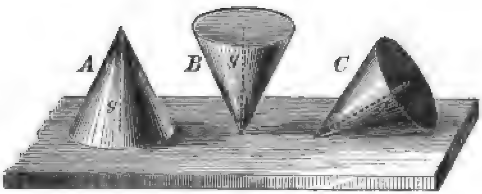


Fig. 31.

63. Stability of Bodies. — From what has been said in the preceding articles, it follows that bodies will in general be most stable when their bases are largest. For in such cases, even after a considerable inclination, the line of direction of the weight will pass within the original base, and the weight will act to return the body to its original state of rest. Hence chairs, lamps, candlesticks, and many other familiar utensils, are constructed with broad bases, to render them more stable.

The leaning tower of Pisa is so much inclined that it appears about to fall; yet it stands, because the vertical through the centre of gravity passes within the base of the tower. Fig. **32** represents

a tower at Bologna, which is even more inclined than that at Pisa. This tower was built in the year 1112, and received its inclination from unequal settling of the ground on which it was built. It does not fall, because the vertical through the centre of gravity, *G*, passes within its base.

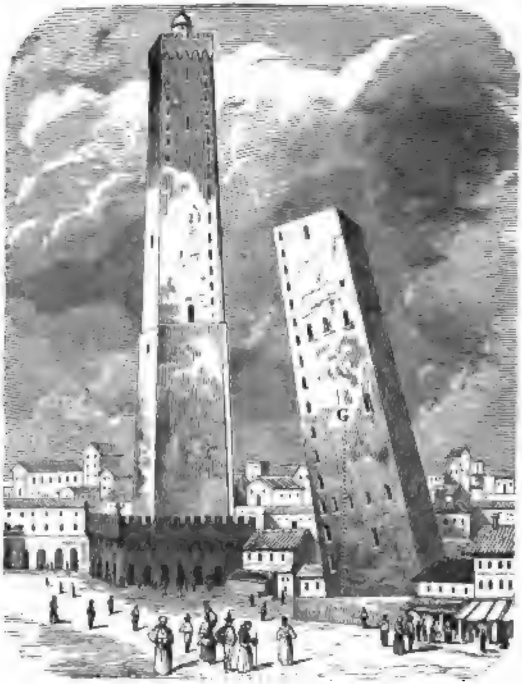


Fig. 32.

In the cases considered, the position of the centre of gravity remains the same for the same body. With men and animals the position of the centre of gravity changes with every change of attitude, which requires a proper adjustment of the feet, to maintain a position of stability.

When a man carries a burden, as shown in Fig. 33, he leans forward, that the direction of his own weight with that of his burden may pass between his feet. When a man carries a weight in one

hand, as shown in Fig. 34, he throws his body toward the opposite side for the same reason.

In the art of rope-dancing, the great difficulty consists in keeping the centre of gravity exactly over the rope. To attain this result the more easily, a rope-dancer carries a long pole, called a balancing pole, and when he feels himself inclining towards one side, he advances his pole towards the other side, so as to bring the common centre of gravity over the rope, thus preserving his equilibrium. The rope-dancer is in a continual state of unstable equilibrium.

Fig. 33. Fig. 34.

Summary.—

Gravitation.

Law of Universal Gravitation.

Motion of Planets in their Orbits.

Terrestrial Gravity.

Law of Terrestrial Gravity.

Gravity at Different Places on the Earth's Surface.

Vertical and Horizontal Lines.

Weight an Effect of Gravity.

Centre of Gravity.

Line of Direction.

Position of Centre of Gravity in Bodies of various Forms.

Equilibrium.

Centre of Gravity in Stable Equilibrium.

Illustrations.

Equilibrium (continued).
Unstable Equilibrium.
Position of Centre of Gravity.
Neutral Equilibrium.
Position of Centre of Gravity.
Examples.
Stability of Bodies.
Leaning Towers.
Equilibrium of Men and Animals.
Rope-dancing.

64. Laws of Falling Bodies. — When bodies starting from a state of rest fall freely in a vacuum, that is, without experiencing any resistance, they conform to the following laws: —

1. *All bodies fall equally fast.*
2. *The velocities acquired during the fall are proportioned to the times occupied in falling.*
3. *The spaces passed over are proportional to the squares of the times occupied in falling.*


Fig. 35.

The first law is verified by the following experiment. A glass tube, six feet long (Fig. 35), is closed at one end, and at the other it has a stop-cock, by which it can be closed or opened at pleasure. A small leaden ball and a feather are introduced within the tube. So long as the tube is full of air, if it be suddenly inverted, it will be observed that the ball reaches the bottom sooner than the feather. If now the air be exhausted by means of an air-pump, and the tube suddenly inverted, both the ball and the feather will be seen to fall through the length of the tube in the same time. This experiment, besides verifying the law, shows also that the air

offers a resistance, which is greater for light than for heavy bodies. This resistance is proportional to the surface offered to the direction of the fall.

2. The second law is a consequence of Inertia combined with the continued action of gravity.

Let a body fall from a state of rest, and at the end of the first second it will have acquired a certain velocity. If gravity should then cease to act, the body would, in consequence of its inertia, continue to fall at the same uniform rate. But the continued action of gravity during the next second generates the same velocity as in the first, and this added to the velocity acquired during the first second gives the velocity at the end of two seconds, which is twice that which is attained at the end of the first second.

So also the velocity at the end of two seconds added to that acquired during the third second will make the velocity at the end of the third second three times as great as at the end of the first second. In the same way it may be shown that the velocity at the end of the fourth second will be four times as great as at the end of the first, and so on.

The space through which a body will fall, under the influence of gravity alone, during the first second is found by experiment to be about $16\frac{1}{12}$ feet. Its *average* velocity during the first second is therefore $16\frac{1}{12}$ feet per second.

Now, as the body begins to fall from a state of rest, or at the velocity of zero, it follows that its velocity at the *end* of the first second will be just twice its average velocity *during* that second, or $32\frac{1}{6}$ feet per second.

This is the *increment of velocity*, i. e. the amount by which the velocity is increased during each second of the body's descent. Taking the average velocity of the descent during the first second as unity, the velocities at the end of each successive second will be represented by the series of even numbers 2, 4, 6, 8, etc.

3. To estimate the space through which the body passes during each second of its descent, let 1 represent the space described during the first second. Then, in consequence of its acquired velocity alone, the body would in the next second pass through two such spaces, while the continued action of gravity will carry it through one space, making the total descent 3, that is, three times that of the first second.

Then at the beginning of the third second, the body having acquired a velocity of 4, its inertia alone will carry it through four spaces, and the action of gravity during this second will add one space, making the whole space traversed in the third second equal 5.

In the same way it can be shown that the spaces traversed during the succeeding seconds will be indicated by the series of odd numbers 7, 9, 11, etc.

It will be seen that the numbers of this series may be obtained by adding one to each of the even numbers representing the velocities, taking zero to represent the initial velocity.

4. The total space passed through at the end of any given time may be found by adding the numbers which denote the space passed through during each successive second; thus, at the end of the fourth second, we find, by adding the numbers 1, 3, 5, 7, that the total space is represented by the number 16.

It will be seen that this sum is always equal to the square of the number of seconds during which the body is falling.

This agrees with the third law of falling bodies, as previously stated.

These results are shown in the following table: $16\frac{1}{12}$ft. = the unit of space.

Number of Seconds.	Velocities at the End of each Second.	Spaces traversed during each Second.	Total Number of Spaces traversed.
1	2	1	1
2	4	3	4
3	6	5	9
4	8	7	16
5	10	9	25
6	12	11	36
etc.	etc.	etc.	etc.

From the principles here developed we derive the following rules: —

1. To find the velocity acquired by a falling body at the end of any given time,

Multiply $32\frac{1}{6}$ ft. by the number of seconds in the given time.

EXAMPLE. Find the velocity of a falling body at the end of the fifth second.

$$32\tfrac{1}{6}\text{ft.} \times 5 = 160\tfrac{5}{6}\text{ft., Ans.}$$

2. To find the space passed over during any given second of the descent,

Multiply $16\frac{1}{12}$ *ft. by that one in the series of odd numbers which corresponds to the number of the second.*

EXAMPLE. Find the space traversed by a falling body during the fourth second of its descent.

$$16\tfrac{1}{12}\text{ ft.} \times 7 = 112\tfrac{7}{12}\text{ ft., Ans.}$$

3. To find the whole distance traversed by a falling body during a given time,

Multiply $16\frac{1}{12}$ *ft. by the square of the given number of seconds.*

EXAMPLE. Find the whole distance traversed by a falling body in six seconds.

$$16\tfrac{1}{12}\text{ ft.} \times 36 = 579\text{ ft., Ans.}$$

65. Apparatus for verifying the Laws of Falling Bodies. — When bodies are allowed to fall freely from a height, it is not easy to compare, or measure accurately, the spaces described during each second of their descent. Methods have therefore been devised which diminish the velocity without otherwise changing the character of the motion. The simplest of these methods is that adopted by Galileo. He used an inclined plane, having a groove, down which a heavy ball was made to roll. By making the inclination small, the rate of motion was so reduced that it could be easily measured.

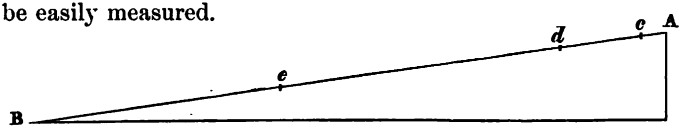


Fig. 36.

In Fig. 36, let the line *A B* represent an inclined plane, and suppose the inclination to be such that a ball placed at *c* will move over the space *c d* in one second. In the next second it will traverse a space, *d e*, three times as great, and in the third second a space five times as great, as in the first second; and so on in the ratio of the series of odd numbers, as given in the table.

By measuring the space described during any given number of seconds, it will be found to be equal to that described during the first

second, multiplied by the square of the number of seconds; thus, if the ball moves one foot in the first second, in three seconds it will move over a space of nine feet. These experiments verify the laws already stated.

66. Bodies thrown perpendicularly upward. — It has been shown that a body falling freely *gains* in velocity $32\frac{1}{6}$ feet during each second of its descent. The force of gravity diminishes an *upward* motion in the same degree that it increases a *downward* motion; hence a body thrown perpendicularly upward will *lose* in velocity $32\frac{1}{6}$ feet during each second of its ascent.

The number of seconds during which it will continue to rise may therefore be found by dividing its initial velocity, or that with which it was projected upward, by $32\frac{1}{6}$.

For example, a body thrown upward with a velocity of $128\frac{2}{3}$ feet per second, will continue to rise during four seconds.

Having found the time, the whole distance to which the body will rise is easily ascertained; for it is the same as the distance through which the body would fall in the given time.

EXAMPLE. Suppose a body thrown upward with a velocity of 193 feet per second, to what distance will it rise?

$$193 \div 32\tfrac{1}{6} = 6;\ 16\tfrac{1}{12} \times 36 = 579 \text{ ft. Ans.}$$

67. Projectiles. — *A body thrown into the air at any angle is called a projectile.* Suppose a ball is fired from A in the horizontal direction AF. If the force of gravity did not act, the ball would move uniformly in the direction AF, passing over equal spaces in equal times. If the ball moved from A to B in one second, it would reach C in two seconds, D in three seconds, and so on. But if the ball were let fall from A without any other force than gravity to act upon it, it would move in a vertical direction, and the spaces AL, LM, MN, etc., described in

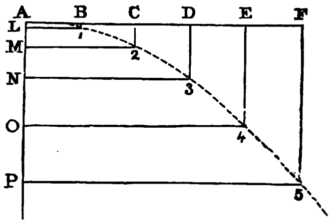


Fig. 37.

successive seconds, would be as the numbers 1, 3, 5, 7, etc. If, now, the ball be acted upon by both these forces, it will be found at the close of each second at the extremity of the diagonal of a parallelogram whose sides represent these separate motions; that is, at the end of the first second it will be found at 1, at the end of the next second at 2, at the end of the third at 3, and so on.

The curve thus described is called a *parabola*.

If a ball be fired obliquely upward it will move in a curve of the same kind, but varying according to the angle of elevation, as shown in Fig. 38. The greatest range or horizontal distance will be attained with an elevation of 45°, and the range will be the same for elevations equally above or below 45°, as at 20° and 70°.

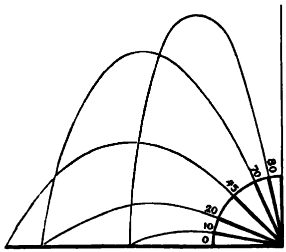


Fig. 38.

These results are correct only for bodies moving in a vacuum. In the case of bodies moving very swiftly through the air, as a cannon-ball or rifle-bullet, the nature of the curve is modified by the resistance of the air. The angle of elevation necessary for the greatest range is also changed to about 40° instead of 45°.

68. Time of a Projectile. — A ball fired horizontally will reach the level ground at the same time as if it were dropped; if fired obliquely upward, it will reach the ground in twice the time required to fall from its highest point of elevation. These results are, however, modified by the resistance of the air.

Summary. —

Laws of Falling Bodies.
- Statement of the Laws.
- Verification of First Law.

Demonstration of Second Law.

Demonstration of Third Law.

Tabular Statement.
- Rules and Examples.
- Galileo's Method.

Bodies thrown upward.
Law and Examples.
Projectiles.
Path of a Projectile.
Time of a Projectile.
Range of a Projectile.

69. The Pendulum. — A PENDULUM is a heavy body suspended from a horizontal axis about which it is free to vibrate. Thus, the ball *m*, suspended from *C* by a string (Figs. 39 and 40), is a pendulum.

Fig. 39.

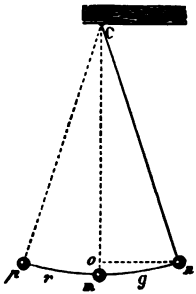


Fig. 40.

When the centre of the ball, *m*, is exactly below the point of suspension, *C* (Fig. 39), it is in equilibrium, for in that position the action of gravity is resisted by the tension of the string. If, however, the ball be drawn aside to *n* (Fig. 40), it is no longer in equilibrium, for in that position the force of gravity acts to draw it back to *m*, at which point it will arrive with the same velocity as though it had fallen through the vertical height *o m*. In consequence of its inertia and acquired velocity, the ball does not stop at *m*, but moves on towards *p*. In descending from *n* to *m*, the force of gravity acts as an accelerating force, but in ascending from *m* to *p*, it acts as a retarding force, hence the ball moves slower and slower until it reaches *p*. The distance *m p* would be rigorously equal to *m n*, were it not for the resistance of the air.

The ball, having reached *p*, is in the same state as it was at *n*; the weight again acts to draw it back to *m*, whence, by virtue of its inertia and velocity, it again rises to *n*, and so on indefinitely.

This backward and forward motion is called *Oscillatory Motion.* A single excursion from *n* to *p* or from *p* to *n*, is called a *Simple Oscillation*, or *Vibration.* An excursion from *n* to *p*, and back again to *n*, is called a *Double Oscillation.* The angle *p C n* is called the angle of the *Amplitude* of the oscillation.

In consequence of the resistance of the air, the amplitude is con-

tinually diminishing, and the ball eventually comes to rest, though often not till after the lapse of some hours.

70. Simple and Compound Pendulums. — A SIMPLE PENDULUM is such a pendulum as would be formed by suspending a single material point by a string destitute of weight.

Such a pendulum may exist in theory, and is thus useful in arriving at the laws of oscillation, but in practice it can only be approximated to by making the ball very small and the string very fine.

A COMPOUND PENDULUM is any heavy body which is free to oscillate about a horizontal axis.

It may be of any form, but in general it consists of a stem, T (Fig. 41), which is either of wood or metal. The stem terminates above in a thin and flexible plate, a, usually of steel; it terminates below in a disk of metal, L, called the ball, which is of a lenticular shape, that the resistance of the air to its motion may be as little as possible.

71. Laws of Oscillation of the Pendulum. — The oscillations of the pendulum take place in accordance with the following laws: —

1. *For pendulums of unequal lengths, the times of oscillation are proportional to the square roots of their lengths.*

2. *For the same pendulum, the time of oscillation is independent of the amplitude, provided the amplitude be small.*

3. *For pendulums of the same length, the time of oscillation is independent of the nature of the material.*

Pendulums of wood, iron, copper, glass, all being of the same length, will all oscillate in the same time.

4. *For the same pendulum at different places, the times of oscillation are inversely as the square roots of the force of gravity at those places.*

These laws are deduced from a course of mathematical reasoning on the theoretical simple pendulum, but they may be verified experimentally by employing a very small ball of platinum, or other heavy metal, and suspending it with a very fine silk thread.

To verify the first law with such a pendulum, we begin by making it vibrate, and then counting the number of vibrations in one minute. Suppose, for example, that it makes seventy-two per minute. Now make the string four times as long as before, and it will be found that the pendulum makes only thirty-six oscillations per minute. If the string is made nine times as long as in the first instance, it will be found that the pendulum makes only twenty-four oscillations per minute, and so on. In the second case the time of oscillation is twice as great, and in the third case it is three times as great as in the first case. Now, because two, three, etc., are the square roots of four, nine, etc., it follows that the law is verified.

To verify the second law, let the same pendulum oscillate, at first through an arc, *p n* (Fig. 40), and then through any other arc, *r g*; it will be found that the number of oscillations per minute is the same in each case. Hence the law is verified. It is to be observed that the law does not hold true unless the arcs *p n* and *rg* are very small, that is, not more than three or four degrees.

The property of pendulums, that their times of oscillation are independent of the amplitude of vibration, is designated by the name *isochronism*, from two Greek words, signifying *equal times;* oscillations performed in equal times are called *isochronal.*

GALILEO first discovered the fact that small oscillations of a pendulum were isochronal towards the end of the sixteenth century. It is stated that he was led to the discovery by noticing the oscillations of a chandelier suspended from the ceiling of the Cathedral of Pisa.

72. Centres of Suspension and Oscillation. — In the compound pendulum the weight of the suspending-rod and of the ball are to be considered. Since a short pendulum vibrates more rapidly than a long one, it is plain that the parts nearest the point of suspension will tend to vibrate in the shortest time, and those farthest from that point in the longest time. But the whole must move together, and consequently the rapid vibrations of the upper part of the pendulum are retarded by the slower vibrations of the lower part. There is a point, however, where the natural rate of vibration is neither accelerated nor retarded, the accelerating effect of the part above being exactly balanced by the retarding

effect of the part below. This point is called the *centre of oscillation*.

The distance between the point of suspension and the centre of oscillation is to be taken as the effective length of the pendulum.

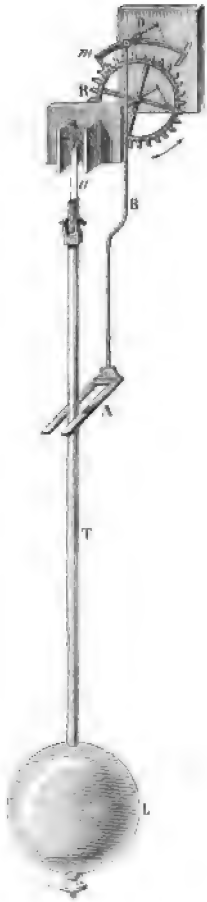


Fig. 41.

73. Applications of the Pendulum. — On account of the isochronism of its vibrations, the pendulum has been applied to regulate the motion of clocks. It was first used for this purpose in 1657, by HUYGHENS, a Dutch philosopher. The motive power of a clock is sometimes a weight acting by a cord wound around a drum, and sometimes a coiled spring similar to a watch-spring. These motors act to set a train of wheel-work in motion, which in turn imparts motion to the hands that move round the dial to point out the hour. It is to impart uniformity of motion to this train of wheel-work that the pendulum is used.

Fig. 41 shows the mechanism by means of which the pendulum acts as a regulator. A toothed wheel, *R*, called a scape-wheel, is connected with the train driven by the motor, and this scape-wheel is checked by an anchor, *m n*, which is attached to the pendulum and vibrates with it. The anchor has two projecting points, *m* and *n*, called pallets, which engage alternately with the teeth of the scape-wheel in such a manner that only one tooth can pass at each swing of the pendulum. The motor turns the scape-wheel in the direction of the arrow until one of the teeth comes in contact with the pallet *m*, which stops the motion of the wheel-work till a swing of the pendulum lifts the pallet *m* from between the two teeth, when a single tooth passes, and the wheel-work moves on until

again arrested by the pallet *n*, falling between two teeth on the other side. A second swing of the pendulum lifts out the pallet *n*, suffers another tooth to pass, when the wheel-work is again arrested by the pallet *m*, and so on indefinitely. The beats of the pendulum being isochronous, the interval of time between the consecutive escape of two teeth is always constant, and thus the motion of the wheel-work is kept uniform. The loss of force which the pendulum continually experiences is supplied by the motor through the scape-wheel and the anchor. This is called the sustaining power of the pendulum.

Owing to expansion and contraction from variations of temperature, the length of the pendulum varies, and according to the first law, its time of vibration changes. In nice clocks this change is compensated by a combination of metals. In common clocks it is rectified by lengthening or shortening the pendulum by a nut and screw, shown at *v*, by means of which the lenticular bob may be moved up and down. In summer the pendulum elongates and the clock loses time, or runs too slow; this is rectified by screwing up the nut and shortening the pendulum. In winter the pendulum contracts and the clock gains time; this is rectified by unscrewing the nut and lengthening the pendulum.

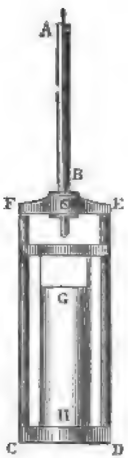


Fig. 42.

74. Compensation Pendulums are made by using two metals in such a way that the expansion of one part downward may be exactly counteracted by the upward expansion of the other part, thus making the effective length of the pendulum always the same.

One of the most common forms is shown in Fig. 42. It is constructed as follows: The pendulum-rod, *A B*, supports a glass jar partly filled with mercury, enclosed in the steel framework, *F C D E*. When the weather is warm, the rod and framework expand and thus increase the length of the pendulum. But at the same time the mercury in the glass jar expands and rises, so that by a proper adjustment the centre of oscillation is carried as far upward by the expansion of the mercury as downward by the expansion of the rod and framework. The distance between the centres of suspension and oscillation remaining the same, the vibrations of the pendulum continue unaltered.

In another form of the compensating pendulum, the ball is supported by a framework composed of rods of different metals, so adjusted that the downward expansion of one part is exactly compensated by the upward expansion of the other part.

In the form shown in Fig. 43, called the gridiron pendulum, there are five steel bars expanding downward and four brass bars expanding upward. As the relative expansibility of brass compared with steel is as 100 to 61, the length of the steel bars is $\frac{100}{61}$ that of the brass.

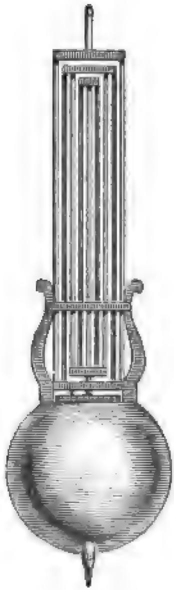


Fig. 43.

75. Length of the Seconds Pendulum. — The length of the pendulum vibrating seconds has been very accurately determined. At the same place it is invariable, but it varies with the latitude. At the equator it is 39.0217 inches; at New York, 39.10237 inches; at Spitzbergen, 39.21614 inches. The cause of this variation is the difference in the force of gravity in different places, due to the spheroidal shape of the earth.

The polar diameter of the earth being twenty-six miles shorter than the equatorial diameter, any point on the surface of the earth near either pole is nearer the centre, and the force of terrestrial gravity is stronger than at points on or near the equator. Consequently, a pendulum which vibrates seconds at the equator, on being carried to a latitude of 40° to 50°, is more strongly acted upon by gravity, and vibrates more rapidly. In order, therefore, that it may continue to make exactly one vibration in each second, the rapidity of vibration must be diminished by increasing the length of the pendulum.

Summary. —

The Pendulum.

Vibration or Oscillation.

Illustration.

Simple Pendulum.

Compound Pendulum.

SECTION III. — WORK AND ENERGY.

76. Work. — The term *work* as used in mechanics means *the production of motion against resistance.*

It is obvious that this definition will apply not only to the labor of men and animals, but to the action of forces of other kinds — as those of wind, water, and steam — when employed in overcoming resistance.

In this sense, drawing loads, raising weights, pumping water, forging iron, pressing cotton, etc., are all examples of work, whatever may be the forces employed in the various operations.

77. Measurement of Work. — The work done in raising a weight to a given height is generally taken as a standard for the measurement of work.

In this country and in England the unit of work commonly adopted is the *foot-pound.*

This is the amount of work required to raise one pound one foot against the force of gravity.

The unit of the Metric System is the work required to

raise one kilogram to a height of one meter. It is called a *kilogram-meter.*

To find a numerical expression for the work in a given example, we multiply the number of weight units raised by the number of linear units in the vertical height to which the body is raised. A weight of 20 lbs. raised 4 feet, or a weight of 4 lbs. raised 20 feet represents 80 *foot-pounds.* A weight of 25 kilograms raised 5 meters represents 125 *kilogram-meters.*

78. **Horse-Power.** — It has been estimated that the strength of a horse is on the average, sufficient to raise 33,000 pounds vertically through one foot in a minute; hence a horse-power is a power which can perform 33,000 units of work in a minute.

The capacity of steam-engines and other powerful machines is generally rated by horse-powers; thus, an engine is said to be of ten horse-power if it is capable of doing work equivalent to raising 33,000 lbs. 10 feet in one minute, or 330,000 lbs. one foot in a minute.

The time required for the work is an essential part of the calculation. If an engine can do 33,000 units of work in half a minute, it is of *two* horse-power; if it can do the same work in one second, it is of *sixty* horse-power.

79. **Energy** is the power of doing work, that is, of overcoming resistance. Any moving body can overcome resistance, and therefore possesses a certain amount of energy. The amount of energy in a moving body depends upon its weight and velocity. The direction in which it moves makes no difference in the energy with which it acts. If its energy is expended in lifting itself against the force of gravity, we can, if its weight and velocity are known, determine the amount of this energy in foot-pounds, or kilogram-meters.

To do this we have simply to find the vertical height to which the given velocity would lift the body, and multiply the weight by the height. Let m = the mass of a body, and v the velocity with which it is moving, and its energy will be expressed by the formula $\frac{1}{2} m v^2$; that is, its energy is equal to *one half its mass multiplied by the square of its velocity.*

80. Kinetic and Potential Energies. — To understand these two types of energy, let us consider the case of a heavy body thrown directly upward into the air. As it begins to rise, it has a certain amount of energy depending upon the velocity with which it moves. This is its *energy of motion.* As it continues to rise, its velocity, and consequently its energy of motion, decreases, until at the highest point which it reaches it has no longer any energy of motion. But in consequence of its elevated position, it has the *power* of doing work in its fall to the earth again; that is, it has *energy of position.*

Energy of motion is called *kinetic* energy.

Energy of position is called *potential* energy.

In the case just given, the sum of the two types of energy remains the same for every position of the body; for, as it rises, kinetic energy decreases, and potential energy increases in exactly the same proportion, while in its descent potential energy decreases and kinetic energy increases till the body comes to rest in its original position.

A body may have energy of position from other causes than being raised to a height.

A bow that is bent, the mainspring of a watch that is wound up, or any body in which reserved force is stored up has potential energy.

Summary. —

Work.
- Definition of Work.
  - Examples.

Measurement of Work.
- Unit of Work.
- The Foot-Pound.
- The Kilogram-Meter.
- Horse-Power.

Energy.
- Measurement of Energy.
- Kinetic Energy.
- Potential Energy.
  - Illustration.
- Examples of Potential Energy.

CHAPTER III.

APPLICATION OF PHYSICAL PRINCIPLES TO MACHINES.

SECTION I. — GENERAL PRINCIPLES.

81. **A Machine** is a contrivance by means of which a force applied at one point is made to produce an effect at some other point.

The force applied is called the *power*, and the force to be overcome is called the *weight*, or load.

82. **Motors.** — The working of a machine requires a continued application of power. The source of this power is called the MOTOR.

Some of the most important motors are *muscular effort*, as exerted by man or beast, in various kinds of work; the *weight and impulse of water*, as in water-mills; the *impulse of air*, as in wind-mills; the *elastic force of springs*, as in watches; the *expansive force of vapors and gases*, as in steam and hot-air engines. The last is, perhaps, the most useful of the motors mentioned.

83. **Object and Utility of Machines.** — The object of a machine is to transmit the power furnished by the motor, and to modify its action in such a manner as to cause it to produce a useful effect.

In no case does a machine add anything to the power applied to it; on the contrary, it absorbs more or less of this power, according to the nature of the work to be done and the connection existing between the parts.

Some of the circumstances which cause an absorption of power

are the rubbing of one part upon another, the stiffness of bands and belts, the resistance of the air, the adhesion of one part to another, and the want of hardness and elasticity in the materials of which the machine is constructed. The resistances arising from these causes are called *hurtful resistances*. They not only absorb much of the power applied, but they also contribute to wear out the machine. The existence of these resistances in every machine requires a continued supply of power to overcome them in addition to that necessary to perform the useful work. Hence the absurdity of attempting to obtain perpetual motion.

84. General Laws of Machines. — The idea of WORK, in mechanics, implies that a force is continually exerted, and that the point at which it is applied moves through a certain space. Thus, in raising a weight, the work performed depends *first* upon the weight raised, and *secondly* upon the height through which it is raised. The *quantity of work* of a force in any given time is measured by the intensity *of the force*, multiplied by *the distance through which it is exerted*. This distance is called *the path described*.

The work of the power is always equal to the work of the load. Hence, if by the use of a machine, a power of one pound can be made to raise a weight of ten pounds, the power must move through ten times the distance traversed by the weight; and as the spaces are traversed in the same time the power must move ten times as fast as the weight.

The power is not necessarily less than the weight; for a machine may be so constructed that a power of ten pounds will be required to lift a weight of one pound; but in this case the weight will move through ten times the space, and with ten times the velocity of the power. Machines, therefore, may be used in two ways, — by making the power move with great velocity to move heavy weights very slowly, or by the use of great power to move small weights very rapidly.

In either case the following general laws will apply to machines of all kinds.

t is gained in intensity of force is lost in time, velocity,

or distance; and what is gained in time, velocity, or distance is lost in intensity of force.

2. *The power multiplied by the distance through which it moves is equal to the weight multiplied by the distance through which it moves.*

3. *The power multiplied by its velocity equals the weight multiplied by its velocity.*

SECTION II.—ELEMENTARY MACHINES.

85. Mechanical Powers.—The elementary machines are seven in number, viz., the *cord*, the *lever*, the *inclined plane*, the *pulley*, the *wheel and axle*, the *screw*, and the *wedge*. These seven are called *mechanical powers*. The first three are simple elements; the remaining ones are combinations of these three.

86. Cords, and BANDS or BELTS, are used for transmitting motion from one point to another, as in the pulley. Chains are often employed for the same purpose, as in the watch.

Cords, belts, and chains should be as flexible as is consistent with sufficient strength.

87. The Lever.—A LEVER is an inflexible bar free to turn about a fixed point, called the *Fulcrum*, and acted upon by two forces which tend to turn it in opposite directions. The force which acts as a motor is called the *Power;* the other one is called the *Weight*, or Load.

Levers may be either straight or curved. The distances from the fulcrum to the lines of direction of the power and weight are called *lever arms*.

In the lever MN (Fig. 44), F is the fulcrum, MP and NR are the lines of direction of the power and weight, FA is the lever arm of the power, and FB is the lever arm of the weight.

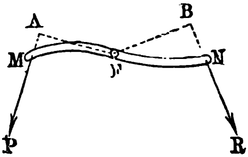


Fig. 44.

Levers are divided into *three classes:*

In the *first class* (Fig. 45), the fulcrum is between the power and the weight.

In the *second class* (Fig. 46), the weight is between the power and the fulcrum.

In the *third class* (Fig. 47), the power is between the weight and the fulcrum.

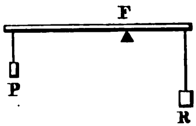


Fig. 45.

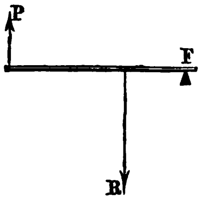


Fig. 46.

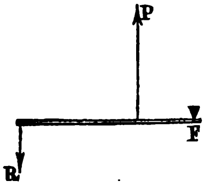


Fig. 47.

88. Law of the Lever. — ***The product of the power multiplied by its distance from the fulcrum is equal to the product of the load multiplied by its distance from the fulcrum.***

EXAMPLES. In a lever of the first kind 8 feet long with the weight 2 feet from the fulcrum a power of 10 pounds will balance a weight of 30 pounds.

In a lever of the second kind, 8 feet long, with the weight 2 feet from the fulcrum, a power of 10 pounds will balance a weight of 40 pounds.

In a lever of the third kind 8 feet long, with the power 2 feet from the fulcrum, a power of 10 pounds will balance a weight of $2\frac{1}{2}$ pounds.

89. Examples of Levers. — Levers are of continual use in the arts, forming component parts of nearly every machine.

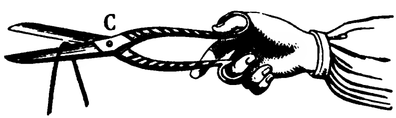


Fig. 48.

A pair of scissors affords an example of the first class of levers. The fulcrum is at *C* (Fig. 48), the hand furnishes the power, and the substance to be cut the resistance.

The common balance, yet to be described, is a lever of this class, as is also the handle of a pump.

The ordinary nut-cracker is an example of levers of the second class. The fulcrum is at C (Fig. 49); the power is the hand, and the resistance is the nut to be cracked.

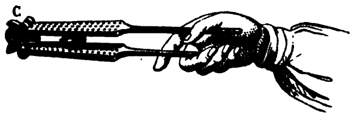


Fig. 49.

The common crow-bar is used as a lever of the first kind when it is pressed downward over the fulcrum to raise a weight (Fig. 50). When one end rests on the ground as a fulcrum, and the other is lifted upward to raise the weight, it becomes a lever of the second kind (Fig. 51).

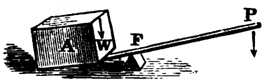


Fig. 50.

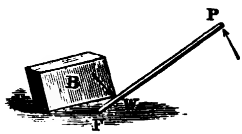


Fig. 51.

The oars of a boat are levers of the second class. The end of the oar in the water is the fulcrum, the hand is the power, and the boat, or rather the resistance of the water which it has to overcome, is the resistance. The shears employed for cutting metals belong to this class of levers.

The limbs of animals are examples of levers of the third class. The figure shows how the human arm acts as a lever.

The socket of the bone a is the fulcrum; a strong muscle $b\,c$, attached near the socket, is the power; and the weight of the limb and whatever resistance w may oppose

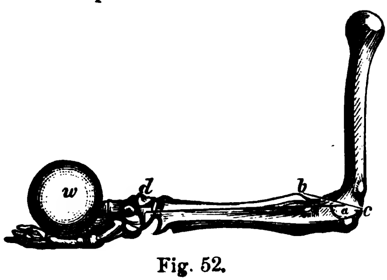


Fig. 52.

to motion is the weight. The fore-arm and hand are raised through a space of one foot by the contraction of a muscle applied near the elbow, moving through less than $\frac{1}{12}$ that space. The muscle, therefore, exerts 12 times the force with which the hand moves.

90. Weight between two Supports. — If a weight is attached to a beam or pole which rests upon two supports, the beam acts as a lever of the second class, and the part carried by either support may be found by considering it as the power and the other support as the fulcrum. If the weight rests on the middle of the beam, it is obvious that each support will bear half the burden. If, as shown in Fig. 53, the load is one-third the length of the beam from *A*, the support *A* will bear two-thirds of the weight.

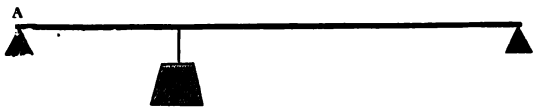


Fig. 53.

91. Compound Levers. — When a small force is required to sustain a considerable weight, and it is not convenient to use a very long lever, a combination of levers, or a compound lever, is employed. When such a system is in equilibrium, *the power, multiplied by the continued product of the alternate arms of the levers, commencing from the power, is equal to the weight multiplied by the continued product of the alternate arms, commencing from the weight.*

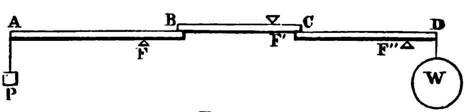


Fig. 54.

For example, the system represented in Fig. 54, consisting of three levers of the first class, will be in equilibrium when

$$P \times AF \times BF' \times CF'' = W \times DF'' \times CF' \times BF.$$

If the long arms are 6, 4, and 5 feet, and each of the short arms 1 foot, then 1 pound at *A* will sustain 120 pounds at *D*.

92. The Balance. — A BALANCE is a machine for weighing bodies.

Balances are of continual use in commerce and the arts, in the laboratory, and in physical researches; they are consequently extremely various in their forms and modes of

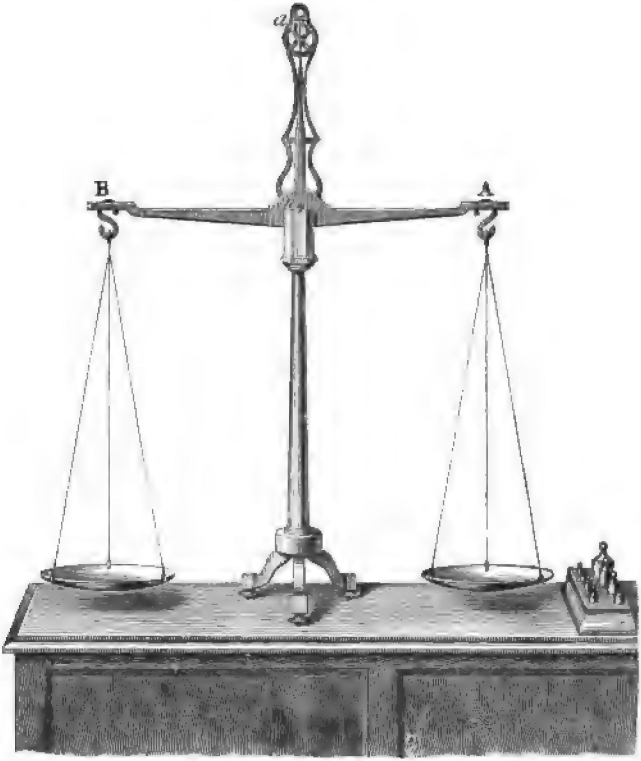


Fig. 55.

construction. We shall only describe one of the forms which is in common use in the shops.

It consists of a metallic bar, *A B* (Fig. 55), called the *Beam*, which is simply a lever of the first order. At its middle point is a knife-edged axis *n*, called the ***Fulcrum.***

The fulcrum projects from the sides of the beam, and rests on two supports at the top of a firm and inflexible standard. The knife-edged axis, and the supports on which it rests, are both of hardened steel, and nicely polished, in order to make the friction as small as possible. At the extremities of the beam are suspended two plates or basins, called *Scale-Pans*, in one of which is placed the body to be weighed, and in the other the weights of iron or brass to counterpoise it. Finally, a needle projecting from the beam, and playing in front of a graduated scale a, serves to show when the beam is exactly horizontal.

To weigh a body, we place it in one of the scale-pans, and then put weights into the other pan until the beam becomes horizontal. The weights put in the second pan indicate the weight of the body.

93. Requisites for a good Balance. — A good balance ought to satisfy the following conditions: —

1. The lever arms, An and Bn, should be exactly equal.

We have seen, in discussing the lever, that its arms must be equal, in order that there may be an equilibrium between the power and resistance when these are equal. If the arms are not equal, the weights placed in one scale-pan will not indicate the exact weight of the body placed in the other.

2. The balance should be *sensitive;* that is, it should turn on a very small difference of weights in the two scale-pans.

This requires the fulcrum and its supports to be very hard and smooth, so as to produce little friction. By making the needle long, a slight variation from the horizontal will be more readily perceived.

3. The centre of gravity of the beam and scale-pans should be slightly below the edge of the fulcrum.

If it were in the edge of the fulcrum, the beam would not come to a horizontal position when the scales were equally loaded, but would remain in any position where it might chance to be placed. If it were above the edge of the fulcrum, the beam would remain

horizontal if placed so; but if slightly deflected, it would tend to overturn by the action of the weight of the beam.

The nearer the centre of gravity comes to the edge of the fulcrum, the more accurate it will be; but at the same time it would turn more slowly, and might finally come to turn too slowly to be of use for weighing.

It is to be observed that when the scale-pans are heavily loaded, an increased weight is thrown on the fulcrum, which causes an increase of friction, and consequently a diminution of sensitiveness.

94. **Methods of testing a Balance.** — To see whether the arms are of equal length, let a body be placed in one scale-pan, and counterbalanced by weights put in the other; then change places with the body and the weights. If the beam remains horizontal after this change, the arms are of equal length; otherwise the balance is *false*.

To test the sensitiveness, load the balance and bring the beam to a horizontal position, then deflect it slightly by a small force and see whether it returns slowly to its former position. It ought to come to a state of rest by a succession of oscillations.

95. **To weigh correctly with a false Balance.** — To weigh a body with a false balance, place it in one scale-pan and counterbalance it by any heavy matter, as shot or sand, placed in the other pan. Then take out the body and replace it by weights which will exactly restore the equilibrium of the balance. The weights will be exactly equal to the weight of the body. The reason for this method is apparent.

96. **The Steel-Yard.** — The common steel-yard used in weighing is a lever of the first class, which differs from the balance in having unequal arms. Fig. 56 represents a form in common use.

The pivot C is the fulcrum; the weight W is suspended from the hook A, and the power P is movable on the long arm of the lever, which is graduated to indicate pounds and ounces. It is evident that a pound weight at D will balance as many pounds at

W as the distance *A C* is contained times in *D C*. The same counterpoise *P* may be used for a greater weight by turning the bar over and suspending it from another pivot *E* nearer the hook *A*. In this case a pound weight at *D* will balance as many pounds at *W* as the distance *A E* is contained times in *D E*.

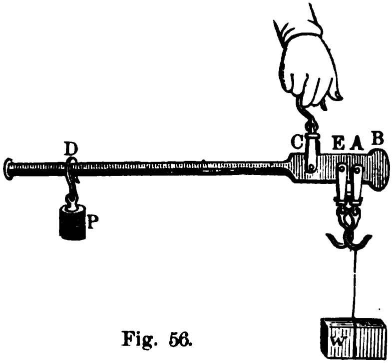


Fig. 56.

The scales used for weighing coal, hay, etc., are generally compound levers, and their operation depends upon principles already explained.

Summary.—

Principles of Machines.
- Definition of a Machine.
- Power and Weight.
- Motors.
- Utility of Machines.
- Loss of Power.

General Laws of Machines.
- Quantity of Work, how estimated.
- General Law of Work.
- Three Laws relating to Intensity of Force, Velocity, and Distance or Space.

Mechanical Powers.
- Elementary Machines.

The Cord.

The Lever.
- Power, Weight, Fulcrum.
- Three Classes of Levers.
- Law of the Lever.
  - Illustrations — The Scissors, Nut-crackers, the Crow-bar, Oars, Limbs of Animals.
- Weight between two Supports.
- Compound Lever.

The Balance.
- Description.
- Requisites for a good Balance.
- Methods of Testing.
- Weighing with a false Balance.
- The Steel-Yard.
- Scales for Great Weights.

97. **The Wheel and Axle** consists of a wheel, or drum, *A*, mounted upon an axle, *B*. The power is applied at one extremity of a cord wrapped around the wheel, and the resistance at one extremity of a second cord wrapped around the axle in a contrary direction. The whole is supported on a suitable frame, by means of pivots projecting from the ends of the axle.

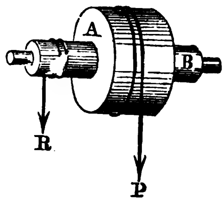


Fig. 57.

The wheel and axle acts as a perpetual lever of the first kind, the fulcrum being at the common centre, and the radii of the wheel and axle being respectively the arms of the lever.

In Fig. 58, *F* is the fulcrum, *A F* is the power arm, and *F B* the weight arm of the lever. Hence, according to the law of the lever, $P \times AF = W \times FB$.

It is evident that during one revolution of the wheel and axle the power moves through a space equal to the circumference of the wheel, and the weight through a space equal to the circumference of the axle. Hence, according to the second general law of machines, the power multiplied by the circumference of the wheel is equal to the weight multiplied by the circumference of the axle.

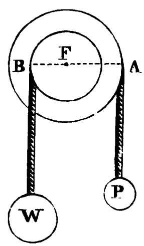


Fig. 58.

Since the radii of circles are proportional to their circumferences, the law of the wheel and axle may be stated in two ways, viz.: —

The power multiplied by the radius of the wheel equals the

weight multiplied by the radius of the axle; or the power multiplied by the circumference of the wheel equals the weight multiplied by the circumference of the axle.

98. **The Windlass.** — The WINDLASS consists of an axle, or arbor, AB, and a crank, BCD, by means of which it is turned. The crank consists of an arm, BC, perpendicular to the axle, called the *crank arm*, and a second arm, DC, perpendicular to the first, called the *crank handle*. The power is applied to the crank handle, and the resistance to a rope wrapped around the axle. The windlass is principally used in raising weights.

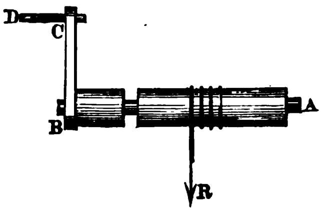


Fig. 59.

99. **The Capstan** is a form of the windlass in which the axis is vertical. It is used chiefly on shipboard for raising the anchor or drawing the vessel up to the dock. The head of the capstan is pierced with holes, in each of which a lever may be placed so that a number of men can work at the same time.

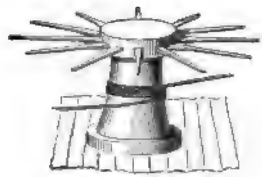


Fig. 60.

100. **The Differential Windlass.** — This differs from the common windlass in having an axle formed by two drums, A and B, of different diameters. A cord is attached to the larger cylinder, and wrapped several times around it, after which it passes under a movable pulley, C, and is then wrapped in a contrary direction around the smaller cylinder. The power is applied to the crank arm, and the resistance to the block of the movable pulley.

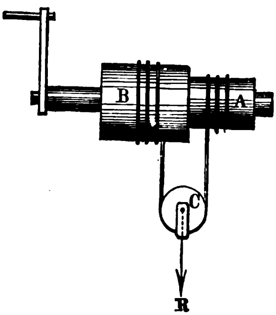


Fig. 61.

When the handle is turned so as to wind up the rope on the cylinder *B*, it is at the same time unwound from the cylinder *A*, and at each revolution the rope is shortened only by the difference in the circumferences of the cylinders. If these are nearly equal, the weight moves very slowly and great power is gained.

101. Trains of Wheels. — The power furnished by the motor of a complex machine is usually transmitted through a succession of pieces to the working point. These connecting pieces are, in general, wheels and axles, and, taken together, they form what is called a *train*. A wheel which imparts motion to a succeeding one is called the *driver*; that to which motion is imparted is called the *follower*.

102. Mode of Connection. — There are various methods by means of which one wheel may be made to act upon another.

First. By simple contact. The driver, *A*, being slightly pressed against the follower, *B*, the friction between the wheels is sufficient to impart a motion of rotation from the former to the latter.

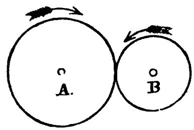


Fig. 62.

To increase the friction and avoid sliding, the surfaces are frequently covered with soft leather. In all cases the motion of the follower is in a contrary sense to that of the driver, as indicated by the arrows.

Secondly. By means of bands or belts. The band is passed around the circumferences of both wheels, and when tightened, a sufficient amount of friction is produced to impart motion from the driver to the follower.

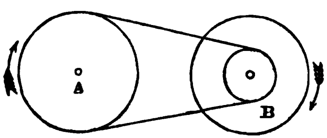


Fig. 63.

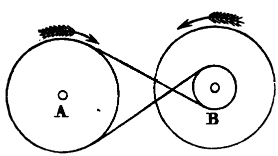


Fig. 64.

When the band does not cross between the wheels, they both revolve in the same direction, as indicated in Fig. 63. When the

band crosses between the wheels, they revolve in opposite directions, as indicated in Fig. 64. Belts are made of leather, gutta-percha, and the like. They are flat and thin, and the drums on which they run should be slightly elevated toward the middle of their thickness. Cords are made of catgut, hempen fibres, or wire, nearly cylindrical. The drums, or pulleys, on which they run, should be elevated at the edges. Chains are also used, and in this case the drums should be grooved, and either notched or toothed, so as to fit the links of the chain.

Thirdly. By means of projections on the circumferences of the wheels called *teeth*.

A small wheel, *C*, mounted on the axle of a large one, *B*, is called a *pinion*, and its projections are called *leaves*. In the figure, the teeth of the wheel *A* engage with the leaves of the pinion *C*, and the teeth of the wheel *B* engage with the leaves of the pinion *D*. If the wheel *A* is turned in the direction indicated by the arrow, the wheel *B* will revolve in a contrary direction, and the wheel *F* in the same direction. A wheel whose teeth project from its circumference, as shown in Fig. 65, is called a *spur-wheel*.

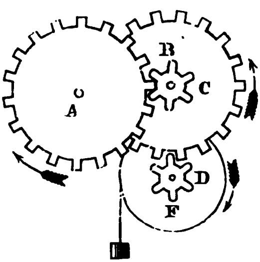


Fig. 65.

103. Law of Wheel-work. — Whatever may be the mode of connection in a train of wheels, the law of their action is the same as that of the compound lever. Hence, *the continued product of the power and the radii of the wheels is equal to the continued product of the weight and the radii of the axles.* For example, in the train shown in Fig. 65, let the radii of the wheels *A*, *B*, and *F*, be represented by the numbers 12, 12, and 8; and the radii of each of the three pinions, by the number 2; then, the power will be to the weight as $2 \times 2 \times 2$ to $12 \times 12 \times 8$, i. e. as 8 to 1152, or as 1 to 144. Suppose a power of 20 pounds to be applied to the first wheel: $20 \times 1152 =$ *Weight* $\times 8$, hence, *Weight* $= 20 \times 1152 \div 8 =$ 2880.

In common clocks and watches we have familiar examples of wheel-work in which the velocity is increased at the expense of the power. Thus, in a watch, the force of the main-spring is applied to a wheel that revolves once in four hours. This force is transmitted through the wheel-work with diminished intensity and increased velocity, to give the second-hand a revolution once a minute.

104. The Pulley. — A Pulley is a wheel free to turn about on its axis and having a groove around it to receive a cord. The axis turns in a frame called a ***block.***

A pulley is said to be *fixed or movable*, according as its block is fixed or movable.

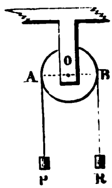


Fig. 66.

105. Single Fixed Pulley. — In this pulley the block, O, is fixed, and the wheel, $A\ B$, turns within it. The effect of the fixed pulley is simply to change the direction of a force.

106. Single Movable Pulley. — In this pulley the block, O, is movable, and the wheel turns within it.

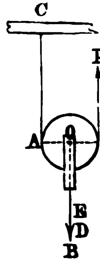


Fig. 67.

Pulleys are combinations of the cord and lever. In the fixed pulley we may regard $A\ B$ as a lever, whose lever arms are $O\ A$ and $O\ B$, and whose fulcrum is O. In the movable pulley we may regard $A\ B$ as a lever of the second class, whose fulcrum is A, and whose lever arms are $A\ B$ and $A\ O$.

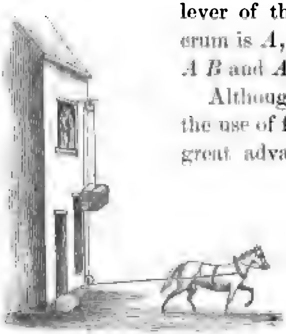


Fig. 68.

Although no power is gained by the use of fixed pulleys, there is often great advantage derived from their use. Thus, a man standing on the ground may, by using a fixed pulley, raise heavy articles to the loft of a warehouse. It is easier to pull the rope downward than to lift the weight upward; but this is not the only advantage gained, for if, instead of using the pulley, he should carry the articles up a flight of stairs, he

would incur the additional labor of lifting his own weight through the whole space. Two fixed pulleys may also be used to change horizontal motion to vertical, as shown in Fig. 68.

107. Combinations of Pulleys. — Movable pulleys are generally used in combination with fixed pulleys. Fig. 69 shows a combination of one fixed with one movable pulley. It is evident that the weight, *W*, is supported equally by the two parts *a* and *b* of the cord which passes around the movable pulley, *A*. Half the weight therefore is supported by the hook, *H*, and the other half by the cord *b*, which passes over the fixed pulley, *B*; and since no power is gained by the fixed pulley, the power, *P*, must be equal to half the weight, *W*, in order to maintain equilibrium. If it be required to *raise* the weight, additional force must be applied at *P*, to overcome friction.

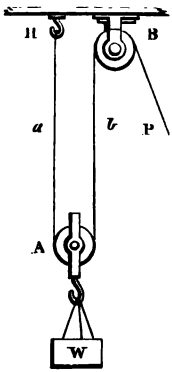


Fig. 69.

In the combinations of pulleys in most common use, several fixed pulleys are contained in one block, and an equal number of movable pulleys in another block. Fig. 70 shows such a combination of two fixed pulleys in the upper block, and two movable ones in the lower block. In this case, one continuous cord passes through the system, and the tension of the weight is equally distributed among the *four* parts of the cord which sustain the lower block. The power applied at *P* is required to balance the weight supported by only one of the parts at *a*; hence the system will be in equilibrium when the power is equal to one fourth of the weight.

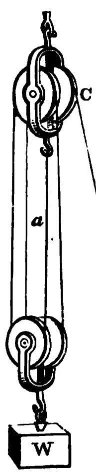


Fig. 70.

The following is the law of such combinations: *The weight equals the power multiplied by the number of parts of the cord that support the movable block.*

Pulleys are often used in combination with other mechanical powers. Cranes and derricks are combinations of wheel-work with pulleys, and are used in raising great weights, as stone in quarries, coal from vessels at the wharves, and for similar purposes.

Summary. —

Wheel and Axle.
- Explained as a Lever.
- The Windlass.
- The Capstan.
- The Differential Windlass.

Trains of Wheels.
- Modes of Connection.
  1. By Simple Contact.
  2. By Means of Bands.
  3. By Teeth.
- Law of Wheel-work.
  - Examples.

The Pulley.
- Single Fixed Pulley.
- Single Movable Pulley.
- Advantage of Fixed Pulleys.

Combinations of Pulleys.
- Illustrations.
- Law of Combined Pulleys.
- Common Applications of Pulleys.

108. The Inclined Plane. — The inclined plane is a hard plane surface which is inclined to a horizontal plane.

When a body rests on a horizontal plane, as for example on a table, the action of gravity tending to draw it down is completely counteracted by the resistance of the plane, and it remains at rest. It is not so, however, when a body is placed upon an inclined plane. In this case the action of gravity may be resolved into two components; one perpendicular to the plane, and the other parallel to it. The action of the first component is counteracted by the resistance of the plane, whilst the second component causes the body to move down the plane.

It is evident that the nearer the plane approaches to a horizontal surface, the greater will be the portion of the weight supported by the surface. Let the plane be elevated toward the perpendicular, and it will support less and less of the weight, till, when it reaches the perpendicular, no part of the weight will be supported.

Whatever may be the inclination of the plane, the action of gravity upon a body placed upon it is resolved into two components which have the same ratio to each other that the perpendicular height of the plane has to the horizontal base.

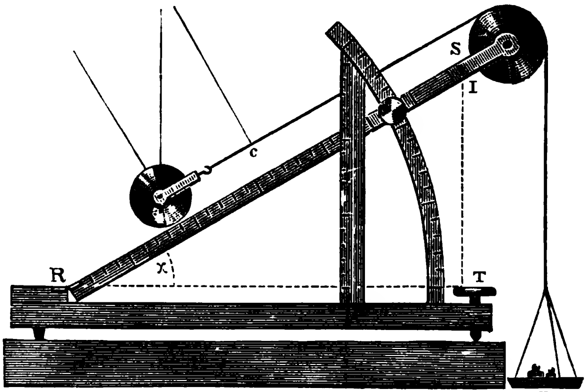


Fig. 71.

Of these two components, that one only which depends upon the perpendicular height must be supported by the power applied to maintain the body in its position.

Hence, *the power is to the weight as the perpendicular height of the plane is to its length.*

Fig. 71 represents a movable inclined plane which may be adjusted so as to form different angles with the horizontal base. If it be arranged so that the plane, *R S*, is twice as long as the height, *S T*, one pound at *P* will balance two pounds on the plane between *R* and *S*. If the height, *S T*, were only one fourth of *R S*, one pound at *P* would balance four on *R S*.

Common roads and railroads are largely made up of inclined

planes, and their inclination is estimated by the height which corresponds to some stated length. Thus, a road is said to rise one foot in thirty, or one foot in fifty. In the case of railroads the inclination is called the *grade*, and is estimated by the number of feet in vertical height corresponding to a mile in length. Thus, we speak of a grade of fifty feet, or eighty feet to the mile.

When a carriage is drawn by horses on a level road, the power is expended in overcoming friction. On a road which rises one foot in twenty, the horses must lift one twentieth of the load, besides overcoming the friction, which varies from one fifteenth to one fiftieth of the load. On railroads the grade is seldom made higher than eighty feet to the mile, a rise of one foot in sixty-six.

109. The Wedge. — The WEDGE is a solid, bounded by a rectangle, *BD*, called the *back;* two rectangles, *AF* and *DF*, called *faces*, and two triangles, *ADE* and *BCF*, called *ends*. The line *EF*, in which the faces meet, is called the *edge*.

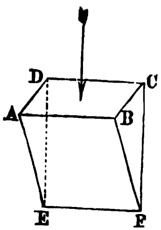


Fig. 72.

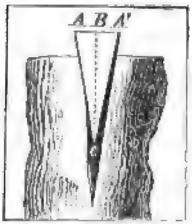


Fig. 73.

The form generally used is the double wedge, represented in Fig. 73. The resistance in this case acting at right angles to the opposite faces of the wedge, the power is to the resistance as half the thickness of the wedge is to its length.

No accurate estimate can be made of the force exerted by a wedge as ordinarily used, for the following reasons: —

1. The power is by exerted blows, the force of which cannot be exactly measured.

2. The surfaces separated often act as levers, and greatly assist the action of the wedge.

3. The friction is much greater than with the other mechanical powers, and cannot be accurately estimated.

If it were not for the friction the wedge would recoil after every blow, and no practical use could be made of it.

Wedges are used where an intense force is to be exerted through a

very small space, and especially for splitting masses of wood or stone, for blocking up buildings, and for raising vessels in docks.

The edges of knives, scissors, chisels, axes, and all cutting instruments are wedges.

110. The Screw. — The SCREW is essentially a combination of inclined planes. It consists of a solid cylinder, enveloped by a spiral projection called the *thread.* The two faces of the thread are nothing more than inclined planes wound around the cylinder of the screw.

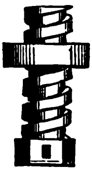


Fig. 74.

The screw works into a solid, fitted to receive it, called the *nut.* The nut may be fixed, the screw turning within it, or the screw may be fixed, the nut turning upon it. Motion is imparted to the one or the other, as the case may be, by means of a lever, at the extremity of which the power is applied. By increasing the length of the lever, and diminishing the distance between the threads, the force exerted at the point of resistance may be almost indefinitely increased.

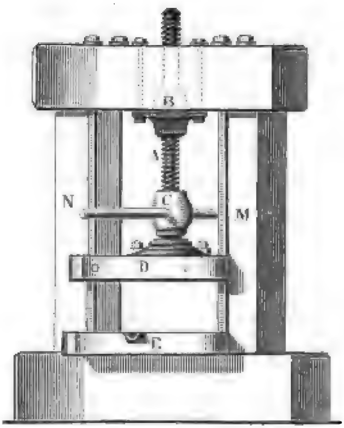


Fig. 75.

Fig. 75 shows the use of the combined lever and screw in producing great pressure. *A* is the screw, *B* the nut, and *E* the block on which the substance to be pressed is placed. The power is applied at the end of the lever, *N*. According to the general law of machines, the force exerted at *D* will be as many times greater than the power applied at *N* as the circumference through which *N* moves is greater than the distance between the threads of the screw.

Suppose the distance between the threads to be one inch, and that the end of the lever, *N*, describes a circle of ten feet in circum-

ference in once turning round, then the ratio of the power to the weight will be as one inch to ten feet, or as 1 to 120.

Now if a man exerts a force of one hundred pounds at the end of the lever, the screw will advance with a force of 12,000 pounds. If the distance between the threads were only half an inch the force would be doubled. Hence it is evident, that, with a moderate power, the screw may be made to exert an enormous mechanical force. It must not be forgotten, however, that the work done upon the body to be compressed can never exceed that done at the point of application of the power; on the contrary, it is always less. In this case there is a loss, by friction, of nearly one fourth of the whole effect.

111. Law of the Screw. — Not taking into account the effects of friction, the law of the screw may be stated as follows: —

The power is to the weight as the distance between two adjoining turns of the thread is to the circumference described by the power.

112. The Endless Screw is a screw secured by shoulders, so that it cannot move in the direction of its length, and working into a toothed wheel. When the screw is turned, it imparts motion to the wheel, which, in turn, may be made to move a train of wheel-work.

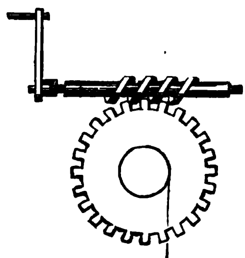


Fig. 76.

Machines of this kind are used in registering the number of turns of an axle, as, for example, the shaft of a steamboat. An endless screw is arranged so as to turn as many times as the shaft, and is connected with a train of light wheel-work. The wheels bear indices, by means of which the number of turns in any given time may be read off. This arrangement is extensively used in gas and water meters, and also in various branches of manufacture.

SECTION III. — RESISTANCES TO MOTION.

113. Friction is the resistance which one body experiences in moving upon another when the two bodies are pressed together. This resistance arises from inequalities in the surfaces, the projections of the one sinking into the depressions of the other. To overcome the resistance thus produced, a force must be applied sufficient to break off, or bend down, the projecting points, or else to lift the moving body over the inequalities.

Friction is distinguished as *sliding* and *rolling*. The former arises when one body is drawn upon another; the latter, when one body is rolled upon another. Everything else being equal, the former is greater than the latter.

114. Measurement of Friction. — The comparative amount of sliding friction for many different surfaces has been determined by the apparatus shown in Fig. 77.

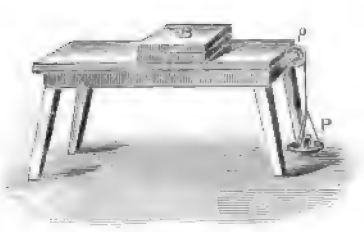


Fig. 77.

Blocks of different materials and of different size and shape, sometimes loaded with weights, were made to move over surfaces of different kinds, by means of weights placed in the pan, *P*. By these experiments the following facts have been ascertained: —

1. *Friction is nearly proportional to pressure.*

2. *Friction is not affected by extent of surface, except within extreme limits.*

The same force is required to draw a brick across a board, whether it rests on its broad face or on its edge.

3. *Friction is greater between soft bodies than hard ones.*

4. *Friction is greater between surfaces of the same materials than between those of different kinds.*

The friction of iron upon iron is greater than that of iron upon copper or brass.

For this reason the axles of railway cars being made of steel, the boxes in which they revolve are made of brass or some other metal.

For the same reason, the axles in the wheel-work of the best watches are made to revolve in holes bored in the harder precious stones. Such watches are said to be "jewelled."

5. *Friction is diminished by polishing or lubricating the surfaces.*

Polishing removes projecting points that would catch against each other and increase friction. The application of lubricants like oils, tallow, black-lead, etc., diminishes friction by filling up minute cavities and smoothing the surfaces.

6. *Friction is greatest at the beginning of motion.*

When surfaces remain long in contact, especially under pressure, the projections of one sink deeper into the depressions of the other, and render it more difficult to separate them.

115. Advantages of Friction. — Although friction occasions a loss of power in the working of machines, it has some advantages.

Common nails and screws would be useless were it not that friction holds them in place. A wedge could not be driven if friction did not hold it and prevent it from rebounding after a blow. A locomotive depends upon friction for its power to draw a heavy train of cars.

Sometimes when great loads are to be moved the friction of the driving wheels upon the rails is not sufficient to prevent slipping, and therefore boxes are provided from which sand may be sifted upon the rails when required, thus increasing the friction and enabling the engine to draw its load.

116. Stiffness of Cords. — When a cord is wound upon a wheel or axle, a certain amount of force is required to bend it. The resistance which the cord thus offers to bending is classed as a hurtful resistance. This resistance should be obviated, as far as possible, by selecting bands and cords which are as flexible as is consistent with due strength.

117. **Atmospheric Resistance.** — The atmosphere exerts a powerful resistance to the motion of bodies moving through it. It has been found, both by theory and experiment, that this resistance is proportional to the greatest cross section of the body, made by a plane perpendicular to the direction of the motion, and also to the square of the body's velocity. To obviate this resistance as far as possible, the pieces which have a rapid motion should have as small a cross section as is consistent with due strength.

Summary.

The Inclined Plane.

Resolution of the Force of Gravity in a body resting on an Inclined Plane.

Law of the Inclined Plane.

Illustration by Movable Inclined Plane.

Common Roads and Railroads.

The Wedge. Reasons why the Force exerted by the Wedge cannot be accurately estimated.

Practical Applications of the Wedge.

The Screw.

Combined Lever and Screw.

Law of the Screw.

The Endless Screw.

Resistances to Motion.

Friction. Sliding and Rolling Friction.

Measurement of Friction.

Six Facts relating to Friction.

Advantages of Friction.

Stiffness of Cords.

Atmospheric Resistance.

CHAPTER IV.

THE MECHANICS OF LIQUIDS.

Part I.—HYDROSTATICS.

SECTION I. — GENERAL PRINCIPLES.

118. Hydrostatics and Hydrodynamics. — The Mechanics of Liquids is divided into two branches: HYDROSTATICS, which treats of the laws of equilibrium of liquids, and HYDRODYNAMICS, which treats of the laws of motion of liquids.

119. Properties of Liquids. — The following properties are common to all liquids:

1. The molecules of liquids are extremely movable, yielding to the slightest force.

There is very little cohesion between the molecules of liquids, whence their readiness to slide among one another. It is to this principle that they owe their fluidity.

2. Liquids are only slightly compressible.

Liquids are so slightly compressible, that for a long time they were regarded as absolutely incompressible. In 1823, OERSTED demonstrated, by an apparatus which he contrived, that liquids are slightly compressible. He showed that for a pressure of one atmosphere, that is, of 15 pounds on each square inch of surface, water is compressed the $\frac{49}{1000000}$th of its original volume. Slight as is the compressibility of water, it is nevertheless ten times as compressible as mercury.

3. Liquids are porous, elastic, and impenetrable, like other bodies.

That liquids are porous, has already been shown. That they are elastic, is shown by their recovering their volume after the compressing force is removed. It is also shown by the fact that they transmit sound. Their impenetrability is shown by plunging a solid body into a vessel filled with liquid. If there is no imbibition, a volume of water will flow over the vessel just equal to that of the solid introduced.

Upon these three properties of liquids depends their property of transmitting pressures in all directions.

120. Transmission of Pressures. — Principle of Pascal. — Let a bottle be filled with water and corked, as represented in Fig. 78. If the cork be pressed inwards, the pressure will be transmitted to the molecules in contact with it; these molecules will in their turn press upon the neighboring ones, and so on until the pressure is finally transmitted to every point of the interior surface of the bottle.

Fig. 78.

It is shown by experiment that the pressure thus transmitted is equal to that applied to the cork; that is, the pressure upon each square inch of the interior surface of a vessel is equal to that upon a square inch of the cork. The pressure is everywhere perpendicular to the surface, as shown by the arrow-heads.

This principle is called the *Principle of Pascal*, because it was first demonstrated by BLAISE PASCAL in the seventeenth century. Upon it depends the whole theory of Hydrostatics.

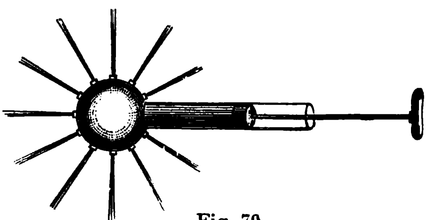


Fig. 79.

The same principle may be shown by another experiment. A cylinder (Fig. 79) provided with a piston is fitted into a hollow sphere. Perpendicular to the sides of the globe are small tubular openings. Fill the cylinder and globe with water, and press the piston against the water, and it will come from all the orifices equally, and not merely from that which is opposite the piston.

121. Pressure due to the Weight of Liquids. — If a cylindrical vessel is filled with a heavy liquid, its weight produces a pressure upon the walls of the vessel. If we suppose the liquid divided into horizontal layers of equal thickness, it is plain that the second layer from the top supports a pressure equal to the weight of the first, the third layer supports a pressure equal to the weight of the second and first, and so on to the bottom. Hence, *the pressure upon any layer is proportional to its depth below the upper surface, and is equal to the weight of the column of fluid above it.*

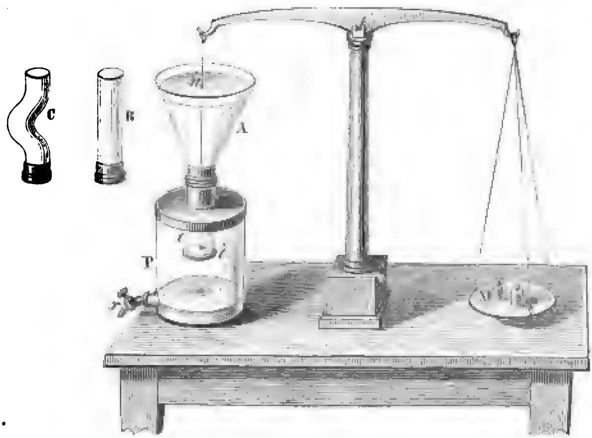


Fig. 80.

In consequence of the Principle of PASCAL, this pressure is transmitted laterally, and acts against the sides of the vessel with an equal intensity. Hence, *every part of the surface is pressed with a force equal to the weight of a column of liquid whose base is the surface pressed, and whose height is equal to the distance from that surface to the upper level of the fluid.*

122. The Pressure on the Bottom of a Vessel, arising from the weight of a liquid, is entirely independent of the shape of the vessel, as well as of the quantity of liquid which it contains. It depends only on the size of the sur-

face pressed, and its distance below the upper surface of the liquid.

This principle may be demonstrated by means of an apparatus shown in Fig. 80. The apparatus consists of a tube, *o*, firmly attached to the cover of a glass vessel, *P*. By means of a screw joint, different-shaped vessels, *A*, *B*, *C*, may be attached to the upper end of the tube. A disk, *i*, of ground glass is held in contact with the lower end of the tube by a string, which is secured at its upper extremity to an arm of a balance.

The vessel *A* is screwed on, and filled with water until the downward pressure exactly counterpoises a given weight in the scale-pan, *M*, when the upper surface of the water is marked by a sliding bead, *n*. The other vessels, *B* and *C*, are successively screwed on, and filled with water up to the level, *n*; if any more water is poured into either, the downward pressure overcomes the weight, *M*, and the water escapes into the vessel, *P*.

This principle of pressure on the bottom of vessels is sometimes called the *Hydrostatic Paradox*. It is so called, because the same pressure may be obtained by using very different quantities of the same liquid.

123. Hydrostatic Bellows. — A good illustration of the principle that the pressure exerted by a column of water depends upon its height and not its amount is seen in a form of apparatus called the *hydrostatic bellows*. It consists (Fig. 81) of two boards connected by leather, in which a tube, *A*, is inserted.

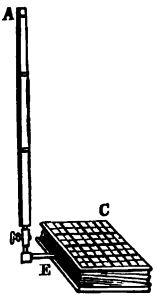


Fig. 81.

When water is poured into the tube a pressure is exerted upon the upper board *C*, which will lift a weight as many times greater than the weight of the water in the tube, as the area of the board is greater than the area of a cross-section of the tube.

By placing another tube upon *A*, we can increase the pressure and lifting power.

124. Lateral Pressures. — Reaction Wheel. — The fact that liquids exert lateral pressures upon the walls of vessels is demonstrated by means of the reaction wheel.

This wheel is shown in Fig. 82; it consists of a vertical cylindrical tube, *C*, turning freely in a ring, *n*, near its upper extremity, and resting upon a pivot at its lower extremity. Just above the pivot the tube terminates in a cubical box, from the faces of which project four tubes, having their ends curved, as represented in the figure. Water is supplied from a cistern through the funnel, *D*. When the water is admitted, it flows down the tube, *C*, and escaping through the curved tubes at the bottom, the wheel is turned in the direction indicated by the arrowhead.

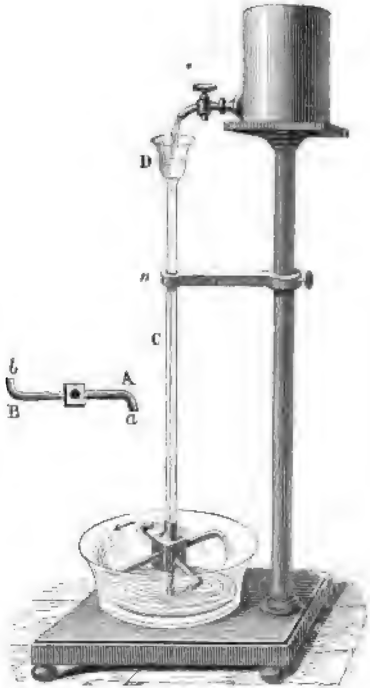


Fig. 82.

The reason of this will be plain from a consideration of the small figure, *a b*, which is a plan of two of the tubes. The weight of the water causes a pressure upon *A*, which, were *a* closed, would be exactly counterbalanced by the pressure upon it; but *a* being open, the pressure upon *A* is not counterbalanced, but acts from *a* towards *A*, producing rotary motion. The pressures in all of the tubes conspire to produce rotation in the same direction.

125. Pressure Upwards. — That liquids exert a pressure upwards is demonstrated by means of the apparatus shown in Fig. 83.

It consists of a tube of glass, with a movable disk, *a*, ground so as to fit the bottom of the tube. The disk being held closely against

the tube by a string, *b*, the whole is plunged into a vessel of water. In this state the disk, though heavier than the water, does not fall to the bottom, showing that it is held in place by an upward pressure. If water now be poured into the tube in a gentle stream, the disk will adhere till the latter is filled to the level of the fluid on the outside. This shows that the upward pressure is equal to the weight of a column of water whose base is that of the tube, and whose altitude is its distance below the upper surface of the fluid.

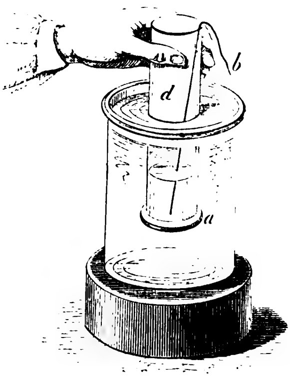


Fig. 83.

The upward pressure of fluids is called their *Buoyant Effort.* It is in consequence of their buoyant effort that fluids sustain lighter bodies on their surfaces. The same principle causes fluids to buoy up bodies of all kinds, diminishing the weight of heavy ones, and causing light ones *to float.*

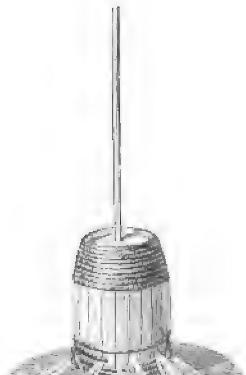


Fig. 84.

126. Pascal's Experiment.—The following experiment was made by Pascal, in 1647. He fitted into the upper head of a strong cask a tube of small diameter and about thirty-four feet in length, as shown in Fig. 84. The cask being filled with water, he succeeded in bursting it by pouring a comparatively small quantity of water into the tube. In this case the pressure exerted laterally was the same as though the tube had been throughout of the same diameter as the cask, or even greater.

127. Hydraulic Press.—The principle of equal pressures has been applied in the construction of a press, by

means of which a single man may exert an enormous power. This press is shown in perspective in Fig. 85, and in section in Fig. 86, the letters in both figures corresponding to the same parts.

The press consists of two cylinders, *A* and *B*, of unequal diameters. In the cylinder *B* is a solid piston, *C*, which rises as the

Fig. 85.

water is forced into *B*, and thus forces up a platform, *K*. The cylinder *A* forms the barrel of a pump, by means of which water is raised from a reservoir, *P*, and forced into the cylinder *B*. This pump is worked by a lever, *O*, attached to a solid piston, *a*. When the piston *a* is raised, a vacuum is formed behind it, which is filled by water from the reservoir, *P*, which enters by opening the valve *S*. When the piston is depressed, the valve *S* closes, the

valve *m* is opened, and a portion of the water is forced through the pipe, *d*, into the cylinder *B*. By continuing to work the piston *a* up and down, additional quantities of water are forced into the large cylinder.

In consequence of the principles of *equal pressures*, the force applied to the piston *a* is transmitted through the tube, *d*, and is finally exerted upwards against the piston *C*, its effect being multiplied by the number of times that the section of the piston *C* is greater than that of the piston *a*. For example, if the section of *C* is 150 times as great as that of *a*, every pound of pressure on the latter will produce 150 pounds of pressure on the former. This effect

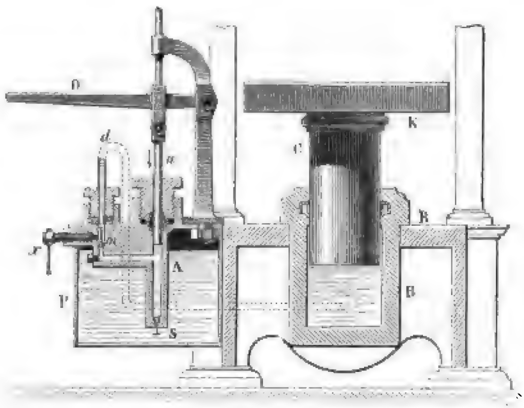


Fig. 86.

is further multiplied by means of the lever, *O*. The pressure exerted upon *C* forces up the platform, *K*, with an energy that may be utilized in compressing any substance placed between it and the top of the press, *M N*. This upward pressure may also be used for raising heavy weights.

By varying the relative dimensions of the parts of the machine, an immense power may be exerted. In the arts, presses of this kind are constructed capable of exerting a force of more than a hundred thousand pounds.

The hydraulic press is used in compressing seeds to obtain oils, in packing hay, cotton, and other goods for shipment, in pressing books for the binder, and in a great variety of other operations.

The immense tubular bridge over the Menai Straits was raised from the level of the water to the top of the piers by means of presses of this description. The hydraulic press was also used in launching the Great Eastern, the heaviest movable structure ever constructed by man.

Summary. —

Hydrostatics and Hydrodynamics.
    Properties common to all Liquids.
Transmission of Pressures.
        Experiment.
    Principle of Pascal.
        Experiment.
Pressure due to the Weight of Liquids.
    Law of Pressure.
    Pressure on the Bottom of a Vessel.
        Hydrostatic Paradox.
    Hydrostatic Bellows.
    Lateral Pressures.
    Reaction Wheel.
    Pressure Upwards.
        Experiment.
    Pascal's Experiment.
    Hydraulic Press.

SECTION II. — EQUILIBRIUM OF LIQUIDS.

128. Conditions of Equilibrium. — A solid body is in equilibrium when its centre of gravity is supported, because the particles of the body are held together by cohesion. In liquids the particles do not cohere, and unless restrained they would flow away and spread out indefinitely. A liquid can be in equilibrium only when restrained by a vessel or something equivalent. Furthermore, each particle must be equally pressed in all directions, which requires that the free surface should be level, that is, everywhere perpendicular to the force of gravity.

In saying that the free surface must be level, we suppose that the liquid is acted upon only by the force of gravity, which is the ordinary case. If, however, it is acted upon by other forces, the free surface must, at every point, be perpendicular to the resultant of all the forces acting at that point; for if it were not so, this resultant might be resolved into two components, one perpendicular to the surface, and the other parallel to it. The former would be resisted by the reaction of the liquid, and the latter, being uncompensated, would produce motion, which is contrary to the hypothesis of equilibrium.

Fig. 87.

129. Level Surface. — The surface of a liquid is LEVEL when it is everywhere perpendicular to the direction of gravity. Small level surfaces coincide sensibly with horizontal planes. Large level surfaces are curved so as to conform to the general form of the earth's surface. That the surface of the ocean is curved is shown by the phenomena presented by a ship viewed from the shore, as exhibited in Fig. 87. As the vessel recedes, we first lose sight of her hull, then her lower sails disappear, then her higher sails, until at last the entire vessel is lost to view.

In defining a level surface, we said that it is everywhere perpendicular to the direction of gravity; more strictly speaking, it is perpendicular to the resultant of gravity and the centrifugal force due to the earth's rotation on its axis. Were it not for the centrifugal force, the surface of the ocean would be perfectly spherical, but in consequence of that force, it is ellipsoidal; that is, the oceans are elevated about the equator and depressed about the poles.

The general level of the ocean is called the ***true level;*** a horizontal plane at any point is called the ***apparent level.***

The curvature of the earth is about eight inches per mile, and increases as the square of the distance.

Fig. 88.

130. Equilibrium of Liquids in Communicating Vessels.

— When a liquid is contained in vessels which communicate with one another, it will be in equilibrium if its upper surface in all of the vessels is in the same horizontal plane.

This principle is demonstrated by means of the apparatus represented in Fig. 88. This apparatus consists of a system of glass vessels of different shapes and capacities, all of which communicate by a tube, *a c*. If any amount of water or other liquid be poured into one of the branches and allowed to come to rest, it will be seen

that its upper surface in all of the vessels is in the same horizontal plane. The reason of this is, obviously, a necessary consequence of the principle of equal pressures.

131. Vessels containing Liquids of different Densities. — When liquids of different densities are contained in communicating vessels, they will be in equilibrium when the heights of the columns are inversely as their densities.

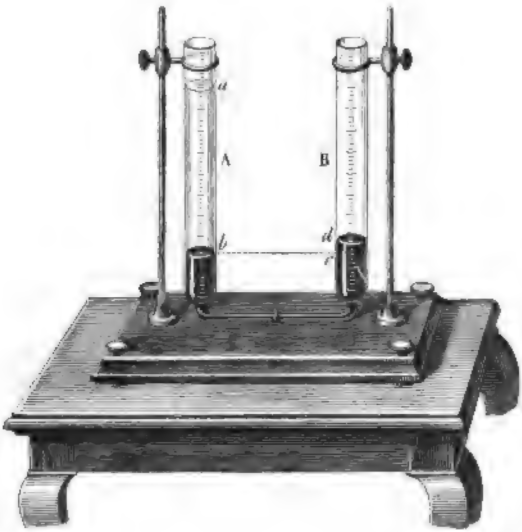


Fig. 89.

This principle is demonstrated by means of an apparatus shown in Fig. 89. The apparatus consists of two glass tubes, *A* and *B*, open at top, and communicating at bottom by a smaller tube. If a quantity of mercury be poured into one of the tubes, it will come to a level in both tubes, according to the principle explained in the preceding article. If a quantity of water be poured into the tube *A*, the level of the mercury in that tube will be depressed, whilst it will be elevated in the tube *B*. The difference of level, *d c*, can be determined by the graduated scales on the tubes. It will be found by measurement, that the column of water, *a b*, is 13.6 times as high as the

column of mercury, *d c*, which it supports. It will be shown hereafter, that mercury is 13.6 times as dense as water; hence the principle is proved. Other liquids may be employed with similar results.

132. Equilibrium of Heterogeneous Liquids. — If liquids of different densities, but which do not mix, be poured into a vessel, they will arrange themselves in the order of their densities, the heaviest being at the bottom, and the upper surface of each will be horizontal.

This is shown by a vial (Fig. 90) containing liquids of different densities, as mercury, water saturated with potassium carbonate, alcohol reddened by aniline, and naphtha. We can float on the different surfaces balls of cork, wax, wood, and glass. If the vial be shaken, the liquids appear to mix; but if allowed to stand, they arrange themselves in horizontal layers, the densest liquid at the bottom.

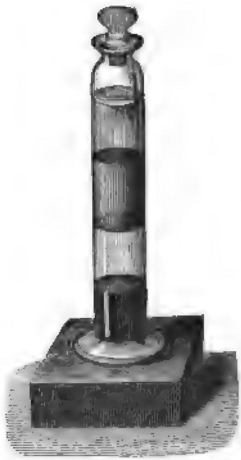


Fig. 90.

It is in accordance with this principle that cream rises on milk, and oil on water. The principle is often employed to separate liquids of different density by the process of decanting.

SECTION III. — APPLICATIONS OF THE PRINCIPLE OF EQUILIBRIUM.

133. The Water Level. — A Water Level is an instrument employed for determining the difference of level between two points. It consists of a horizontal tube of metal $2\frac{1}{2}$ or 3 feet in length, into the extremities of which two glass tubes are inserted perpendicular to it. The whole

rests upon a three-legged support, called a *tripod*, as shown in Fig. 91. A quantity of water tinged with carmine or other coloring matter is introduced into one of the glass tubes, which, flowing through the horizontal tube, rises to the same level in the other, by the principle of equilibrium of liquids in communicating vessels. A visual ray directed along the surfaces of the water in the two glass tubes will be a horizontal line, or a *line of apparent level.*

In using the instrument, the square, seen at the left of the figure, can be raised or lowered to agree with the dotted line.

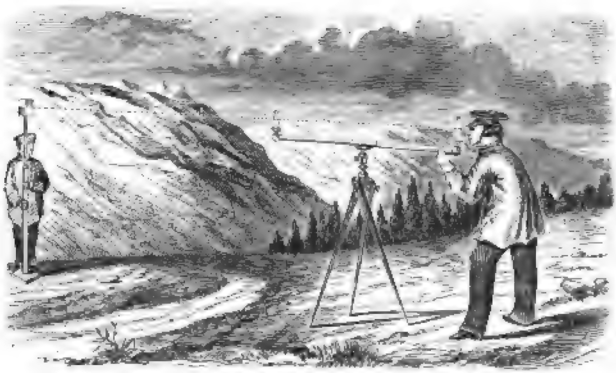


Fig. 91.

The difference of level will be the difference between the height of the levelling instrument and the distance of the horizontal mark on the square from the ground.

134. The Spirit Level. — The SPIRIT LEVEL consists of a tube of glass nearly filled with alcohol, and closed at its two extremities. The tube is slightly curved, and when placed horizontally, the bubble of air which it contains rises to the middle of the upper side of the tube. If either end be depressed, the bubble runs toward the other end. When used it is ordinarily mounted in a wooden case.

This form of *level* is much used by masons, carpenters, and other

artisans. To ascertain whether a surface is level, the instrument is laid upon it, and the position of the bubble noticed. If the bubble is in the middle of the tube, the surface is level.

In the level used by carpenters there are generally two tubes in the same case situated at right angles to each other, — one for horizontal surfaces, the other for vertical.

The form of level shown in Fig. 92 is attached to many kinds of surveying and astronomical instruments.

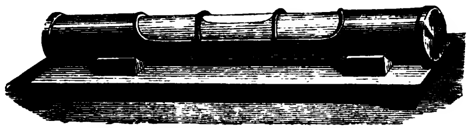


Fig. 92.

135. Springs. — Fountains. — Rivers. — It is the principle of equal pressures that causes water to rise in springs and fountains. The water which feeds them is contained in natural or artificial reservoirs higher than the spring or fountain. These reservoirs communicate with the springs or fountains by natural or artificial channels, and the pressure of the water in them causes that in the spring or fountain to boil up, or sometimes to shoot up in a jet.

The water of a jet tends to rise to the level of that in the reservoir, and would do so were it not for the resistance of the air, the friction of the water against the pipe, and the resistance offered by the falling particles, all of which combine to render the jet lower than the fountain-head.

The same principle determines the flow of streams from the higher to the lower grounds. The water of lakes, seas, and oceans is continually evaporating to form vapors and clouds. These are condensed in the form of rain, and the particles of water, urged by their own weight, seek a lower level. The rivulets gather to form brooks, and these unite to form rivers, by which the water is once more returned to the oceans and lakes. All of the water does not flow back to the ocean along the surface, but a portion percolates through the porous soils and accumulates in cavities to feed our springs and wells.

Fig. 93 represents a fountain. The reservoir is on the hill to the left, and the water reaches the bottom of the basin by a pipe represented by dotted lines.

It will be observed that the column of water does not rise as high as the position occupied by the water in the reservoir on the hill, for the reasons just given.

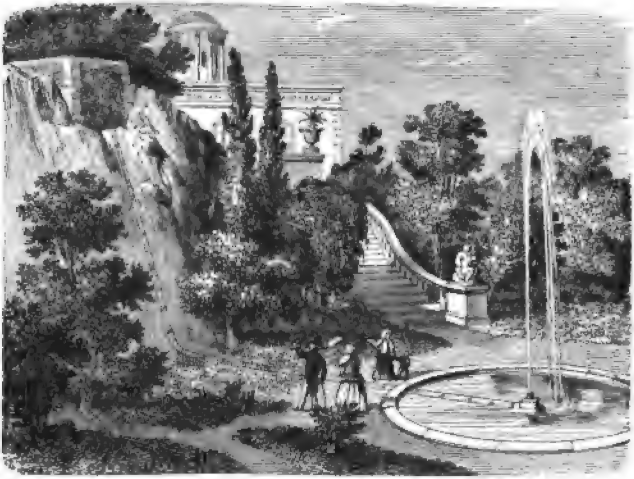


Fig. 93.

136. Artesian Wells are deep wells, formed by boring through rocks and strata of various kinds of earth to reach a supply of water. These wells are named from the province of Artois, in France, where they were first used.

Fig. 94 illustrates the principle of these wells. *H* is the natural surface of the earth. *A B* and *C D* are curved strata of clay or rock which do not allow of the percolation of water. *K K* is an intermediate stratum of sand or gravel, which permits water to penetrate it. When a hole, *I*, is bored down to strike the water-bearing stratum, *K K*, the pressure of the water in the stratum forces it up in a jet. The well of Grenelle, in Paris, is nearly 1800 feet deep, and is fed by water coming from the hills of Champagne, which are much higher than Paris. The supply of water from this well is immense.

Many Artesian wells have been sunk in our own country. There are two in St. Louis, one of which reaches the depth of 3843.5 feet, and one in Columbus, Ohio, having a depth of $2775\frac{1}{3}$ feet. In California these wells are used in providing water for irrigation.

The so-called ***flowing wells*** of the oil regions of Pennsylvania are examples of Artesian wells. In some cases, however, the cause of the violent outburst which often takes place, when the reservoir containing petroleum is first penetrated, is the pressure of confined air and gases.

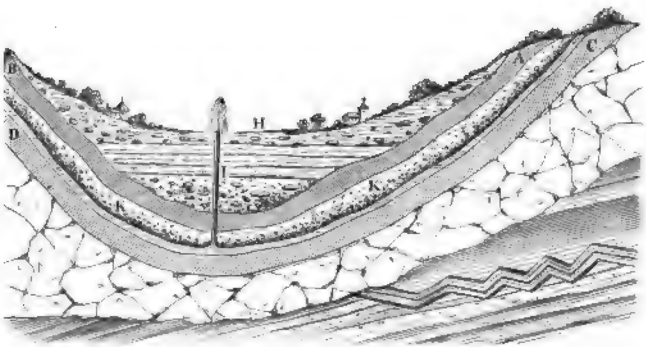


Fig. 94.

The water of many Artesian wells contains great quantities of common salt and other substances in solution.

Summary. —

Equilibrium of Liquids.

Conditions of Equilibrium.

Level Surface.

Apparent and True Level.

Liquids in Connected Vessels.

Illustration.

Liquids of different Densities.

1. In Communicating Vessels.
2. In the same Vessel.

Applications of Principle of Equilibrium.

The Water Level.
The Spirit Level.
Springs, Fountains, Rivers.
Artesian Wells.
Flowing Wells.

SECTION IV. — PRESSURE ON SUBMERGED BODIES.

137. Principle of Archimedes. — If a body is submerged in a fluid, it will be pressed in all directions, but not equally.

To illustrate, suppose a cube immersed in water, as shown in Fig. 95. The lateral faces, *a* and *b*, will be equally pressed and in opposite directions. The same will be true for the other lateral faces. Hence the horizontal pressures will exactly neutralize each other. The upper and lower faces, *c* and *d*, will be unequally pressed, and in opposite directions. The face *c* will be pressed upwards by a force equal to the weight of a column of the liquid whose cross-section is that of the cube, and whose height is the distance of *c* from the surface of the fluid. The face *d* will be pressed downwards by the weight of a column of the liquid, having the same cross-section as the cube, and a height equal to the distance of *d* from the surface of the liquid; the resultant of these two pressures is an upward force, equivalent to the weight of a volume of the liquid equal to that of the cube. This upward pressure is the *buoyant effort* of the fluid.

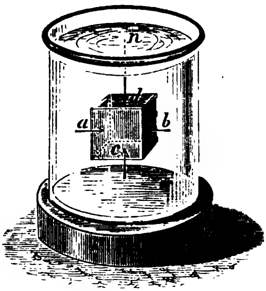


Fig. 95.

The principle just explained is called the *Principle of Archimedes.* It may be expressed by saying that *a submerged body loses a portion of its weight equal to that of the displaced fluid.*

138. A Hydrostatic Balance is a balance having a hook attached to the lower face of each scale-pan, and so constructed that the beam may be raised or lowered at pleasure.

Fig. 96 represents a hydrostatic balance. The cylinder *c* is solid and fitted to slide up and down in the hollow cylinder *d*. The cylinder *c* may be confined in any position by means of a clamp screw, *n*.

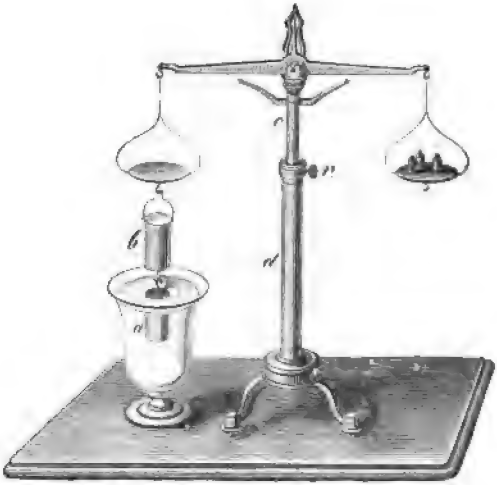


Fig. 96.

139. Cylinder and Bucket Experiment. — The principle of ARCHIMEDES may be illustrated by what is called the *Cylinder and Bucket Experiment*, as shown in Fig. 96. A hollow cylinder or bucket, *b*, of brass, is attached to the hook of one of the scale-pans, and from it is suspended a solid cylinder of brass, just large enough to fill the bucket, and the two are balanced by weights placed in the opposite scale-pan. A glass vessel having been placed beneath the cylinder, water is gradually poured into it, until the cylinder is immersed. The opposite scale-pan will descend, showing

that the cylinder is buoyed up by some force. If we now fill the bucket, *b*, with water, the equilibrium will be restored, and the beam will come to a level. Because the water poured into the bucket is equal to that displaced by the cylinder, we infer that the buoyant effort is exactly equal to the weight of the displaced fluid.

The principle of ARCHIMEDES is so called because it was first discovered by the illustrious philosopher of that name. He was led to the discovery in an attempt to detect a fraud perpetrated upon HIERO of Syracuse by a goldsmith who had been employed to make a golden crown. The artisan mixed a portion of silver with the gold that was given him for making the crown, but, by means of the principle above explained, ARCHIMEDES was able to determine the exact amount of each material employed.

140. Floating Bodies. — Principles of Flotation. — When a body is plunged into a liquid, it is urged downward by its proper weight, and upward by the buoyant effort of the liquid, and, according to the relative intensities of these two forces, three cases may arise : —

1. If the density of the immersed body is the same as that of the liquid, its weight will be equal to the buoyant effort of the liquid, and it will remain in equilibrium wherever it may be placed. This is practically the case with fishes. They maintain themselves in any position in which they may happen to be, without effort.
2. If the density of the body is greater than that of the liquid, its weight will be greater than the buoyant effort, and the body will sink to the bottom. This is what happens when a stone or piece of iron is thrown into water.
3. If the density of the body is less than that of the liquid, its weight will be less than the buoyant effort, and the body will rise to the surface. The body will continue to rise until the weight of the displaced liquid equals that of the body, when it will come to rest. It is then said *to float*. Thus, a piece of wood floats upon water, and in like manner a piece of iron floats upon mercury.

When a floating body comes to rest on a liquid, the plane of the upper surface of the liquid is called the ***Plane of Flotation.***

It sometimes happens that a body which is more dense than a

liquid floats upon it. Thus, a porcelain saucer floats upon water. This arises from its form being such that it displaces its own weight of water when only partially immersed. For the same reason iron ships float freely on the ocean.

141. Illustration of the Principles of Flotation. — The principles of flotation may be illustrated by an instrument shown in Fig. 97, which, under various forms, is sold in the shops as a child's toy.

In the form shown, it consists of a high and narrow glass vessel, surmounted by a brass cylinder, *A*, in which is an air-tight piston that may be raised or depressed by the hand. The vessel is partially filled with water, and contains a light body, as a fish, hollow, and of porcelain or glass. The fish is attached to a sphere of glass, *m*, filled with air, and with a small hole, *o*, at its lower side, through which water can flow in or out, as the pressure is increased or diminished.

Fig. 97.

Under ordinary circumstances the sphere, *m*, with its attached fish, floats at the surface of the water. If the piston is depressed, the air beneath it is compressed, and acting upon the water forces a portion of it into the globe. The apparatus then becomes more dense than the water, and sinks. By relieving the pressure, the air in the globe expands and drives the water out, when it again floats on the surface. The experiment may be repeated at pleasure.

142. Swimming Bladder of Fishes. — In many fishes there is a bladder filled with air, situated directly under the backbone. This is called the *Swimming Bladder*.

When the fish wishes to descend, it compresses this bladder by

a muscular effort, and then, as the quantity of water displaced is less than before, the weight of the fish prevails over the buoyant effort, and the fish sinks. On relaxing the effort, the bladder expands, the buoyant effort of the water prevails over the weight of the fish, and it rises.

143. Swimming. — The human body is lighter than water, especially than the salt water of the ocean, and tends naturally to float when immersed. The only reason why men do not swim naturally is the difficulty of keeping the head out of water, so as to be able to breathe. The head is the heaviest part of the body, and tends continually to sink into the water.

Many quadrupeds swim naturally, because the head is small in proportion to the body, and is so placed upon the trunk that it is easy to keep it above the surface.

The safest position for a person in the water, who does not know how to swim, is upon the back. The tendency to raise the arms out of the water should be resisted, as this diminishes the buoyant effort of the fluid without diminishing the weight.

Many kinds of birds, as ducks, geese, swans, and the like, swim naturally and without effort. They owe this faculty to a thick layer of down and feathers which are very light, and impermeable by water. They therefore displace a large volume of water in proportion to their weight, giving rise to a strong buoyant effort.

Summary. —

Pressure on Submerged Bodies.
- Principle of Archimedes.
  - Illustration.
- Hydrostatic Balance.
- Cylinder and Bucket Experiment.
  - Hiero's Crown.

Floating Bodies.
- Bodies of the same Density as the Liquid. — Bodies of greater Density. — Bodies of less Density.
- Plane of Flotation.
  - Illustration of Flotation.
- Swimming Bladder of Fishes.
- Swimming.
- Why many Animals swim naturally.
- Aquatic Birds.

SECTION V. — SPECIFIC GRAVITY OF BODIES.

144. **The Specific Gravity** of a body is its *relative weight;* that is, it is the number of times the body is heavier than an equivalent volume of some other body taken as a standard.

It is a matter of daily observation that some bodies are heavier than others under the same volume. Thus, gold is heavier than silver, lead than iron, stones than wood, and so on. In order to compare the relative weights of different bodies, all are referred to a common standard.

Distilled water is generally adopted as a standard, and because water varies in density at different temperatures, it is usual to take it at the temperature of 39°.2 Fahrenheit, or 4° Centigrade, water being most dense at that temperature.

In order to find the specific gravity of any body, all that we have to do is to find how many times heavier any given volume of the body is than an equivalent volume of distilled water at 39°.2 F. This is the method of fixing the specific gravity of solids and liquids; we shall see hereafter how it is possible to fix the specific gravity of gases and vapors.

145. **Specific Gravity of Solids.** — The following are some of the methods of determining the specific gravities of solids: —

1. *By the Hydrostatic Balance.* — Place the body in one of the scale-pans and balance it by known weights in the other pan. These will give the weight of the body in air. Next suspend the body in a vessel of distilled water by means of a thread or wire attached to one of the scale-pans, as shown in Fig. 98, and balance it by weights placed in the other pan. On account of the buoyant effort of the water, the weight of the body in water will be less than that in air. Subtract the weight of the body in water from that in air, and the difference will be the weight of the displaced water, that is, the weight of a volume of water equal to that of the body.

Having found the weight of the body in air, and the weight of an equivalent volume of water, divide the former by the latter, and the result will be the specific gravity required.

This method is sometimes briefly stated in the following rule: *Divide the weight in air by the loss in water.*

EXAMPLE. A piece of marble weighs 24 grammes in air and 15.5 grammes in water; what is its specific gravity?

$$24 - 15.5 = 8.5. \quad 24 \div 8.5 = 2.82 +, \text{Ans.}$$

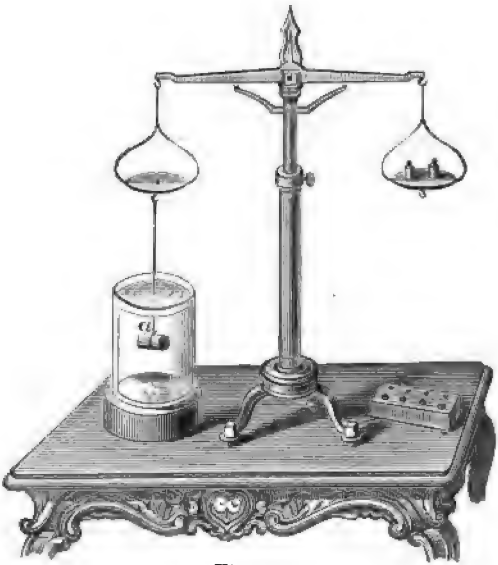


Fig. 98.

The specific gravity of a solid that floats in water may be found by the following method. Attach to it some body heavy enough to sink it, and weigh both together in air, and then in water; and, by subtraction, find how much the combined solids lose in water. Then take the heavy body alone and find how much it loses in water. Subtract this from the loss sustained by the two, and it will give the weight of the water displaced by the lighter body. Now divide the body's weight in air by this remainder and it will give the specific gravity.

EXAMPLE. To find the specific gravity of a piece of wood weighing 6 ounces. Attach to it 8 ounces of lead.

Weight of combined solids in air . . .	14	ounces.
We find their weight in water to be . .	4.5	"
Loss of combined solids in water . . .	9.5	"
Weight of lead alone in air	8	"
Its weight in water is found to be . . .	7.3	"
Lead loses in water	.7	"

The loss due to the wood alone equals $9.5 - .7 = 8.8$. Specific gravity of the wood $= 6 \div 8.8 = .682$ nearly.

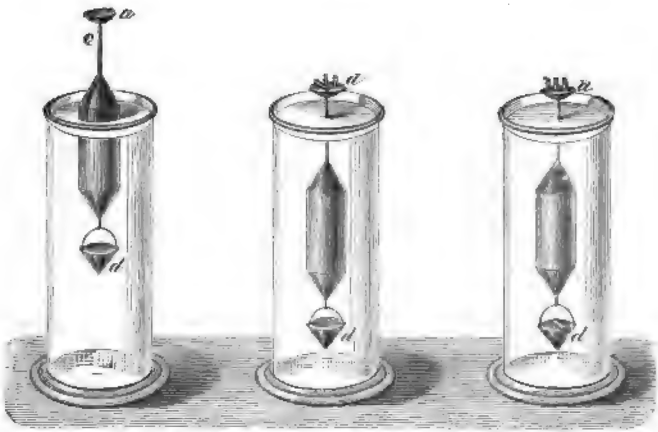


Fig. 99. Fig. 100. Fig. 101.

2. *By Nicholson's Hydrometer.* — NICHOLSON'S HYDROMETER consists of a hollow cylinder of metal, as shown in Fig. 99, weighted at the bottom by a heavy body, *d*, to make it float erect, and terminating above by a thin stem, *c*, which supports a scale-pan, *a*. The instrument is so constructed that when a given weight, say 500 grains, is placed in the pan, it will sink in distilled water to a notch, *c*, on the stem.

The method of determining the specific gravity by means of this instrument is shown in Figs. **100** and **101**. Suppose it were required to determine the specific gravity of a small bar of iron weighing less than **500** grains.

The bar is placed in the pan and weights added till it sinks to the notch in the stem, as shown in Fig. 100. These weights, subtracted from 500 grains, give the weight of the bar in air. Next place the bar in the cup, *d*, as shown in Fig. 101, and add weights enough to make the instrument sink again to the notch in the stem. The last weights will denote the buoyant effort of the fluid, or the weight of the water displaced by the bar. Divide the weight of the bar in air by the weight of the displaced water, and the result will be the specific gravity sought.

3. *By a Flask.* — This method is used when a body exists in a state of powder, or in fine particles like sand. A small flask, whose exact weight is known, is first filled with the powder and the whole carefully weighed. The entire weight, diminished by that of the flask, is the weight of the body. The flask is then filled with water and weighed. This weight, diminished by that of the flask, is the weight of an equivalent volume of water. Divide the weight of the body by that of its equivalent volume of water, and the result will be the specific gravity required.

It is evident that by this method we obtain the specific gravity of the entire contents of the flask as one mass, including the air that it may contain.

146. Specific Gravity of Liquids. — The following are some of the methods of determining the specific gravities of liquids: —

1. *By Fahrenheit's Hydrometer.* — FAHRENHEIT'S HYDROMETER consists of a glass cylinder ballasted at the bottom by a small globe filled with mercury, and provided at top with a stem and scale-pan, as shown in Fig. 102. Its weight is carefully determined.

To use the hydrometer, it is first plunged into distilled water, and weights placed in the scale-pan till it sinks to the notch filed on the stem. These weights, increased by that of the instrument, will give the weight of the displaced water. The instrument is next plunged into the liquid in question, and weights are placed in the pan till the instrument again sinks to the notch. These weights, added to that

of the instrument, give the weight of the displaced liquid. Now the volumes displaced are the same in both cases, each being that of the submerged instrument; hence, if we divide the weight of the displaced liquid by that of the displaced water, the quotient will be the specific gravity required.

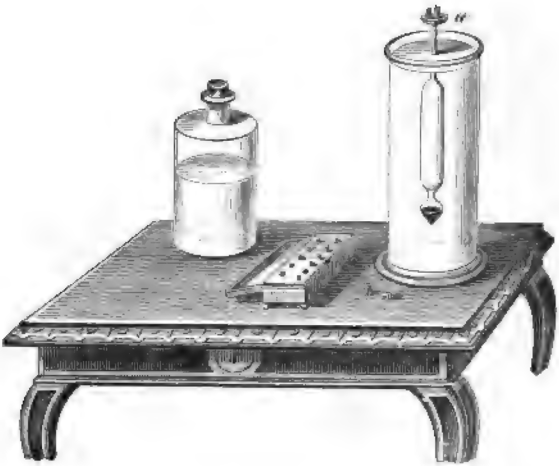


Fig. 102.

2. *By the Flask.* — A flask is constructed so as to hold a given weight of distilled water, say 1000 grains. This flask is first weighed when empty, and then when filled with the liquid in question. The difference of these results is the weight of the liquid, and this, divided by 1000 grains, will be the specific gravity required.

A knowledge of the specific gravities of bodies is of frequent application. In mineralogy it aids in determining mineral species. The jeweller determines by its aid the precious stones. It enables us to find the weight of a body when we know its volume. Thus a cubic foot of lead weighs 11.35 times as much as a cubic foot of water; but a cubic foot of water weighs 1000 ounces, hence a cubic foot of lead weighs 11,350 ounces, or about 709 pounds.

The specific gravities of some of the most important substances are given in the following table: —

Table showing the Specific Gravities of Solids and Liquids.

Platinum (rolled)	22.07	Mercury	13.60
Gold (stamps)	19.36	Sulphuric Acid	1.84
Lead (cast)	11.35	Milk	1.03
Silver (cast)	10.47	Sea Water	1.03
Iron (bar)	7.79	Distilled Water	1.00
Zinc (cast)	6.86	Bordeaux Wine	0.99
Diamond	3.53	Olive Oil	0.91
White Marble	2.84	Spirits of Turpentine	0.87
Glass (flint)	3.33	Absolute Alcohol	0.79
Ivory	1.92	Ordinary Ether	0.72

It will be seen that platinum is the heaviest solid, and that mercury is the heaviest liquid.

147. **Beaumé's Areometer** consists of a bulb of glass, ballasted at bottom by a second bulb containing mercury, and terminating at top in a cylinder of uniform diameter, as shown in Fig. 103.

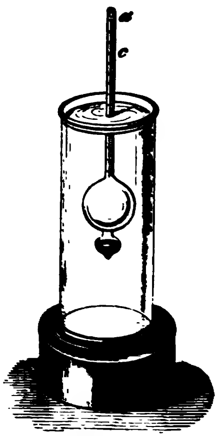


Fig. 103.

When plunged into liquids, it sinks till the weight of the displaced fluid equals that of the areometer. In light fluids it therefore sinks deeper than in heavy ones.

The plan of graduating BEAUMÉ'S areometer is as follows. It is ballasted so that in distilled water it will sink to the point *a*, on the stem, which is marked 0. A mixture of salt and pure water is then formed, in the proportion of 15 of the former to 85 of the latter, into which the instrument is plunged. The upper surface then cuts the stem at some point, *c*, which is marked 15. The intermediate space between *a* and *c* is divided into 15 equal parts, and the division is continued downwards on the stem. The divisions and numbers are on a slip of paper in the interior of the stem.

The use of the instrument thus graduated is to ascertain the amount of salt in any solution of salt in water. It is plunged into

the solution in question, and the number to which it sinks denotes the degree of saturation of the solution.

Instruments constructed on this principle have been devised for determining the strength of other solutions, whether of acids or salts; also for determining the strength of saccharine solutions and the like.

148. The Alcoholmeter is similar in its construction to the areometer just described. It is graduated so as to show the percentage of alcohol in any mixture of alcohol and water.

The instrument is first ballasted so that when plunged in pure water it will float with nearly all of its stem above the water. The line of flotation is marked 0. Mixtures are then formed, containing one, two, three, etc., per cent of pure alcohol and water, and the instrument is plunged into them in succession. The lines of flotation are marked 1, 2, 3, etc., as in the instrument previously. In this case the numbers run upwards. It is necessary to graduate it throughout by trial, as the divisions are not uniform.

Fig. 104.

To use the instrument, it is plunged into the mixture of alcohol and water to be tested, and the percentage is read off on the paper scale within the tube, or else the scale is scratched upon the stem with a diamond.

Summary.—

Specific Gravity.

Standard of Specific Gravity.

Specific Gravity of Solids.

Method by Hydrostatic Balance.

Rule and Example.

Solid Lighter than Water.

Rule and Example.

Method by Nicholson's Hydrometer.

Method by a Flask.

THE MECHANICS OF LIQUIDS.

Part II. — HYDRODYNAMICS.

SECTION I. — FLOW OF LIQUIDS.

149. Flow of Liquids from Orifices. — It has already been shown that the pressure exerted by a fluid is proportional to its depth. If then, in a vessel filled with water, openings be made at different depths from the surface, as shown in Fig. 105, it is evident that the water will flow out with the greatest velocity at the greatest depth from the surface.

But the velocity does not increase in the simple ratio of the depth; it is found to be *in proportion to the square root of the depth.* This result is in accordance with the laws of falling bodies.

The water issues from the jet at v with a velocity which would carry it to the same height with the surface in h, were it not for friction and the resistance of the air.

This velocity is the same that would be acquired by a body in falling freely through the distance from h to v.

Since the whole space described by a falling body is proportioned to the *square* of the time, while the velocity increases in the simple ratio of the time, it follows that the velocity acquired is proportioned to the *square root* of the whole space through which the body falls.

Thus, if an aperture be made in a vessel containing water, $16\frac{1}{12}$ feet

below the surface, the water will escape with a velocity of $32\frac{1}{6}$ feet per second; for this is the velocity acquired by a body falling through that distance.

A stream thrown out in any other direction than the vertical will have the same velocity, since the pressure to which the velocity is due remains the same.

The range of a horizontal jet will be greatest when it is half-way between the surface and the level of the place where it strikes. Thus the jet shown at *m* in the figure has the greatest range. Jets issuing from orifices at equal distances above and below the middle point, as at *g* and *n*, will have the same range.

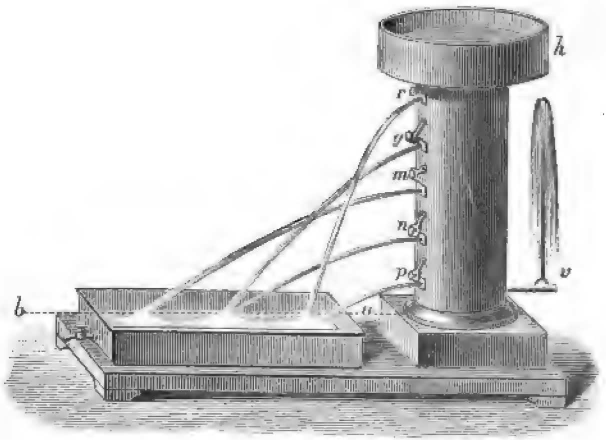


Fig. 105.

150. Volume of Liquid Discharged. — In theory, the volume discharged will be equal to the velocity multiplied by the area of the orifice. For example, if water issues with a velocity of ten feet per second, from an orifice having an area of two square inches, the volume discharged in one second is equal to $(10 \times 12) \times 2 = 240$ cubic inches.

This rule does not give quite accurate results, for in practice the amount discharged is considerably diminished by friction, and by the formation of what is called the *vena contracta*, or contracted vein.

When water flows through a circular opening in a large vessel having thin sides, it rushes from different directions towards the opening and forms conflicting currents that diminish the velocity. On leaving the orifice the jet contracts, so that at a distance somewhat less than the diameter of the opening, the area of its cross section is only about two-thirds of that at the orifice.

This narrow portion of the stream is called the *vena contracta.*

By attaching suitable tubes to the orifice, the formation of the "contracted vein" may be prevented and the flow of water considerably increased.

151. The Flow of Liquids through Pipes.—When water from a reservoir is conveyed to a distance in pipes, the velocity of the flow is greatly diminished by friction, especially in the case of small pipes.

A pipe 200 feet long and one inch in diameter, laid horizontally, will discharge only one-fourth as much water as a tube of the same size one inch long. A pipe of the same length, two inches in diameter, will discharge about five times as much water as one of one inch in diameter. The areas of their cross sections being as the squares of their diameters, the ratio should be as 4 to 1, but the effect of friction in retarding the flow is much greater in proportion in small pipes than in large ones.

152. The Flow of Rivers.—A very slight inclination is sufficient to cause a flow of water. Three inches to a mile in a smooth, straight channel is sufficient to give a velocity of about three miles per hour.

The force of the current in rivers is greatly diminished by friction upon the bottom and upon the banks, and consequently the strongest current is near the surface of the deepest part of the stream.

The parts of a river-bed, where the steepest inclinations occur, are almost always filled with masses of rock, which obstruct the flow and greatly diminish the velocity of the stream.

SECTION II. — WATER AS A MOTIVE POWER.

153. Water-Wheels. — Wherever water is collected in reservoirs or lakes above the level of the sea, it comprises a store of *potential energy* which, by its downward flow, becomes *kinetic energy* — a working power. This power is applied to useful purposes by means of water-wheels. Water-wheels are turned (1) by the force of a current, (2) by the weight of the water, or (3) by both combined.

154. The Undershot Wheel is moved by the force of the current striking against float-boards, which are arranged so as to be more or less submerged.

This is the least effective form of the water-wheel, utilizing not more than twenty-five per cent of the total energy of the stream.

It is generally placed in a "race-way," a narrow, sloping passage which conducts the water from a reservoir or dam. This form of wheel is represented in Fig. **106**.

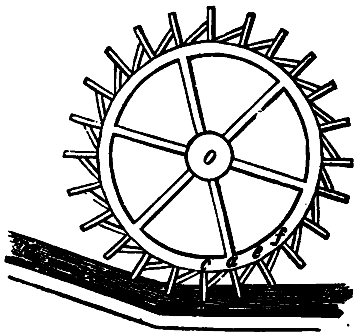


Fig. 106.

155. The Overshot Wheel. — This form of water-wheel is called "overshot" because the water is received at the top and passes over the wheel, as shown in Fig. 107. It is moved principally by the weight of the water, which flows into cells, called "buckets," formed on the circumference of the wheel, and shaped so as to retain as much of the water as possible till they reach the lower part of the wheel, where they are emptied.

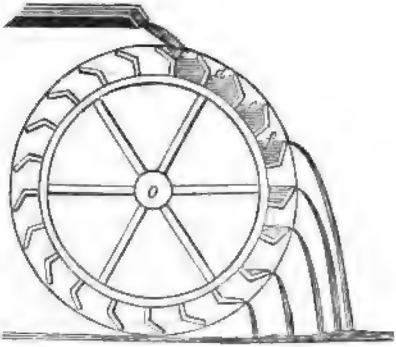


Fig. 107.

This is a very effective form of the wheel, utilizing nearly three-fourths of the total moving power of the water. It is especially adapted for use with a small stream which has a great fall. Wheels of this kind are often made of fifty feet or more in diameter.

156. The Breast Wheel. — In the breast wheel the water is received nearly at the level of the axis. In some wheels of this kind the water flows into buckets similar to those of the overshot wheel; but generally it acts upon float-boards placed perpendicular to the circumference, and the race-way, or passage for the water, is made to fit closely to the circumference of the wheel. The water being thus enclosed acts partly by its weight and partly by its momentum.

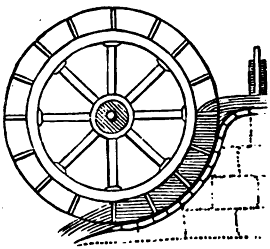


Fig. 108.

Fig. 108. represents this form of water-wheel. In its best form the breast wheel will utilize about sixty-five per cent of the moving power of the water. It was formerly in general use, but is now mostly superseded by the "turbine."

157. The Turbine Wheel is the most effective of all the forms of water-wheels. Many different varieties are in use. One of these is shown in perspective and in horizontal section in Figs. 109 and 110.

The wheel in this form is wholly submerged in water under the pressure of a considerable head. The water enters at the circum-

ferences of the wheel *B*, through an enclosing case, *D*, which is stationary. It is directed by the openings in *D* so as to strike the curved floats or buckets of *B* in the direction of the greatest efficiency. It then escapes from the central part of the wheel by a tube, which is extended vertically downward.

A central shaft, *A* (Fig. 109), communicates motion to the machinery above.

The wheel is protected from the vertical pressure of the water by the top, *T*, which is attached to the enclosing case, *D*.

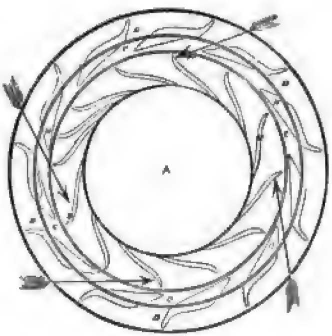


Fig. 109.

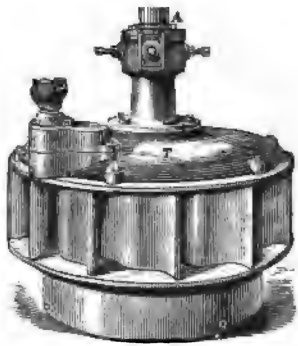


Fig. 110.

In another form of the turbine the water enters through a fixed tube at the centre, and, directed by fixed curved partitions, imparts motion to the outer casing, which revolves, and is connected with the shaft.

The best forms of the turbine, when used under a full head of water, have been found to utilize from eighty to eighty-five per cent of the force of the water.

SECTION III. — MACHINES FOR RAISING WATER.

Most of the machines in common use for raising water depend upon the action of the atmosphere, and will be described under the head of Pneumatics.

158. Archimedes' Screw. — The screw of Archimedes, invented by the philosopher of that name, is one of the most

ancient contrivances for raising water. It was in use before the Christian era, and it is still used in Holland for draining low grounds.

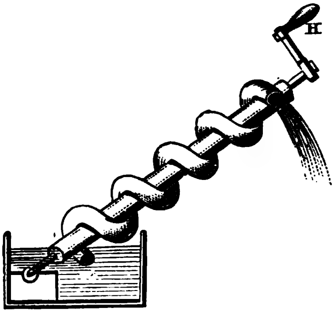


Fig. 111.

As shown in Fig. 111, it consists of a tube wound in a spiral form around a solid cylinder, which is made to revolve by turning the handle, *H*. If placed at a proper inclination, the water, as the handle is turned, will continue to flow into those parts of the tube that are brought successively below the shaft, till finally it will be disharged at the top.

159. The Chain Pump consists of a tube, the lower part of which enters the well or reservoir, and the upper part extends to the point where the water is to be discharged. An endless chain passes over a wheel at the top, and also around another wheel placed in the water at the bottom. This chain carries at equal distances flat disks which fit closely into the tube. As the wheel revolves the disks carry the water before them into the tube, and finally discharge it at the top.

160. The Hydraulic Ram.—When water under a considerable head is flowing through a long pipe, if at any point the flow is suddenly stopped, the momentum of the water causes great and sudden pressure, often sufficient to burst the pipe. The hydraulic ram makes use of this pressure in raising a portion of the water to a greater height.

The principle of its construction is shown in Fig. 112.

The pipe, *A*, leading from the reservoir, terminates in the small cylinder, *B*, which opens upward and is fitted with a valve, *D*, which is heavy enough to fall when the water in the pipe is still, or moving very slowly. When the current through *A* acquires sufficient velocity, it raises the valve and suddenly shuts off the water at *D*.

The sudden pressure thus produced opens the valve *E* leading to an air-chamber, *G*, into which a part of the water is then discharged. The air in the chamber, *G*, is condensed by the sudden influx, but, immediately reacting by its elasticity, it forces a portion of the water up into the small tube, *H*.

As soon as the water in the pipe *B* ceases flowing, the valve *D* opens by its own weight; the valve in the air-chamber closes, and the water again flowing through *A*, soon acquires velocity enough to shut the valve. The whole operation is thus continually repeated; successive portions of water are forced into the air-chamber, and thence, by the elasticity of the confined air, discharged in a continuous stream through the pipe *H*.

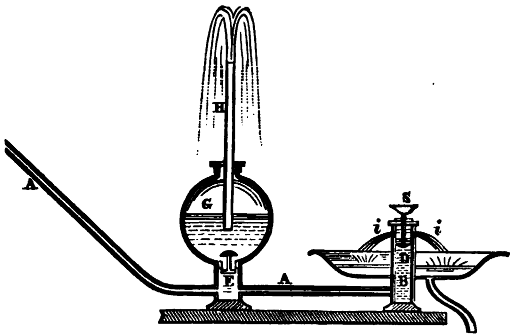


Fig. 112.

The hydraulic ram furnishes a very efficient and economical method of raising a small quantity of water to a great height, wherever a sufficient fall of water can be obtained.

Summary. —

Flow of Liquids from Orifices.

Velocity and Range.

Volume Discharged.

Flow of Liquids through Pipes.

Effects of Friction.

Flow of Rivers.

Potential Energy of Reservoirs of Water.

Water Power — How Applied.

The Undershot Wheel.
The Overshot Wheel.
The Breast Wheel.
The Turbine Wheel.

Methods of Raising Water.

Archimedes' Screw.
The Chain Pump.
The Hydraulic Ram.

CHAPTER V.

PNEUMATICS.

SECTION I. — THE ATMOSPHERE.

161. **General Properties of Gases and Vapors.** — GASES and VAPORS are highly compressible and elastic fluids.

Their particles, like those of liquids, move freely, and transmit pressure in all directions; but they differ from liquids in the predominance of the repellent force exerted between their molecules, in consequence of which a mass of gas always tends to expand.

The force that elastic fluids exert in this way is called their *tension*.

The distinction between a gas and a vapor is not very clear. When a body in the gaseous form can be reduced to a liquid by cooling, or by a moderate pressure, it is usually called a vapor.

It is now known that all the gases may be reduced to the liquid form by great pressure and intense cold combined.

162. **The Atmosphere.** — Common air possesses all the mechanical properties that belong to gases and vapors. It is therefore taken as the *type of aeriform bodies.*

The atmosphere that surrounds the earth is transparent, without odor, and colorless except in great masses. In

masses it assumes a blue tint, and is the cause of the blue color of the sky.

It is composed of *oxygen*, *nitrogen*, *carbonic acid*, *watery vapor*, and some accidental impurities.

The principal ingredients are *oxygen* and *nitrogen*, and these are mixed in the proportion of twenty-one parts by volume of oxygen to seventy-nine parts of nitrogen.

Carbonic acid forms but a small portion of the atmosphere, but it is an constant and very important element. It is continually supplied to the air by the respiration of animals, by the combustion of coal and other fuel, and by the decay of animal and vegetable substances. The burning of a single ton of coal sends into the atmosphere more than three tons of this gas.

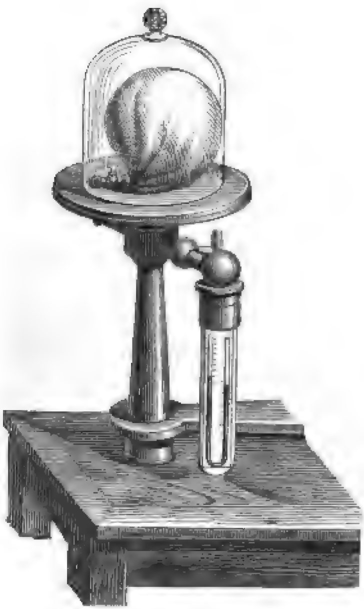


Fig. 113.

On the other hand, all growing plants absorb it and retain the carbon, but restore to the air the oxygen which it contains. It is found that the supply and loss are very nearly balanced, so that the proportion of carbonic acid in the atmosphere remains nearly constant.

It amounts, in volume, to about one part in twenty-five hundred of the whole atmosphere.

163. Expansive Force of Air. — Air and the gases always tend to assume a greater volume.

To show this property, take a bladder or rubber bag, fitted with a stop-cock, as shown in Fig. 113. Press out nearly all the air, then close the stop-cock and place the bag under the receiver of an air-

pump. Then pump the air out of the receiver, and the elastic force of the air in the bag will cause it to expand.

In the same way it may be shown that any gas is expansible.

164. Weight of Air. — Air, like other bodies, has weight.

To show this, take a hollow globe of glass, fitted with a stop-cock, as shown in Fig. 114. Having attached it to one scale-pan of a delicate balance, counterpoise it by weights placed in the other. Then by means of the air-pump exhaust the air from the globe; the opposite scale-pan will descend, and some weights will have to be added to the first scale-pan to restore the equilibrium. The weights added will indicate the weight of the exhausted air.

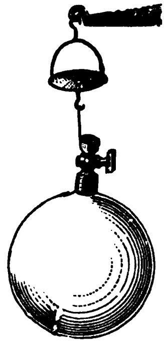


Fig. 114.

165. Atmospheric Pressure. — Since the atmosphere has weight it exerts a pressure on all bodies upon which it rests. This pressure decreases as we ascend into the atmosphere.

If we suppose the atmosphere to be divided into layers parallel to the surface of the earth, it is evident that each layer is pressed down by the weight of all above it. Hence, the higher layers are less compressed than those below them. Being less compressed, they expand, or become *rarefied.* The existence of atmospheric pressure may be shown by a variety of experiments, some of which will be explained below.

166. Bursting a Membrane. — A glass cylinder open at both ends, has its upper end covered by a piece of oiled silk or a stretched membrane, such as is used by gold-beaters, and its lower end is ground so as to fit the plate of an air-pump, as shown in Fig. 115.

In its natural condition, the membrane is pressed down by the weight of the atmosphere above it, and this pressure is resisted by the tension of the air within the cylinder. If now the air be exhausted from the cylinder, the membrane will no longer be pressed from within, and will finally burst with a loud report.

The bursting of the membrane shows the pressure of the air. The report arises from the sudden rush of air to fill up the exhausted cylinder.

If a piece of thin sheet rubber be used in place of the membrane, it will be gradually forced inward as the air is exhausted, and will be stretched in proportion to the degree of exhaustion.

Fig. 115.

167. The Magdeburg Hemispheres. — This apparatus, named from the city where it was invented, consists of two hollow hemispheres of brass, which are ground so as to fit each other with an air-tight joint. The hemispheres are shown in Fig. 116. One of them is so prepared that it can be attached to an air-pump, and is provided with a stop-cock, by means of which a communication with the external air can be opened or closed at pleasure.

The two hemispheres being placed one upon the other, the pressure of the external air is exactly counterbalanced by the tension of

that within, and no obstacle prevents them from being drawn apart. If, however, the air be exhausted from within, the external pressure is no longer counteracted by an expansive force from within, and it requires a considerable effort to effect their separation. We shall see hereafter that the hemispheres are pressed together by a force equal to fifteen pounds, multiplied by the number of square inches in their common cross section.

The experiment was devised by OTTO VON GUERICKE, of Magdeburg. He constructed two hemispheres more than two feet in diameter, and after having exhausted the air, it is reported that it required several horses to draw them asunder.

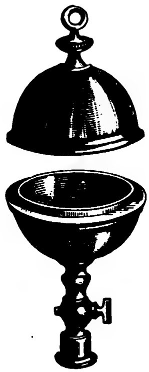


Fig. 116.

168. Upward Pressure of the Air.— Gases, like liquids, transmit pressure in all directions; hence the pressure of the air is exerted not only downwards, but upwards, and in all other directions. This is shown by the experiment with the hemispheres, which are held together with the same force in whatever position they may be placed.

Fig. 117.

The following experiments illustrate the upward pressure of the air: —

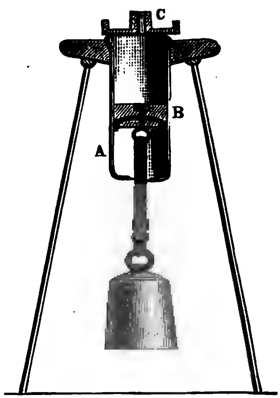


Fig. 118.

Fill a tumbler (Fig. 117) with water, and cover it with a piece of paper; then, holding the paper in contact with the water, invert the tumbler. On removing the hand, if the experiment be carefully made, the water will remain in the tumbler, being held there by the upward pressure of the air. The covering of paper serves to prevent the

air from entering so as to allow the water to escape at the same time.

Fig. 118 represents a glass cylinder, *A*, with a tightly fitting piston, *B*, to which a heavy weight is attached. Let the air be exhausted from the cylinder by an air-pump connected with *C* by a rubber tube, and the weight will be lifted by the upward pressure of the air.

169. Torricellian Tube. — Measure of the Atmospheric Pressure. — The preceding experiments show that the atmosphere exerts a force of pressure; the intensity of that force may be measured by other means.

Fig. 119.

TORRICELLI, a pupil of GALILEO, showed, in 1643, that this pressure amounts to about fifteen pounds on each square inch of surface, at the level of the sea.

In order to repeat TORRICELLI'S experiment, take a glass tube about three feet in length, closed at one end and open at the other. Turning the closed end downwards, let it be filled with mercury. Then holding the finger over the open end, let it be inverted in a vessel of mercury, as shown in Fig. 119. On removing the finger, the mercury sinks in the tube until the column, *A B*, is about 30 inches high, when it comes to a state of equilibrium.

In this condition, the mercury is sustained by the pressure of the air upon the surface of the free mercury in the vessel, transmitted according to the law explained in Art. 119. At the level of the sea, the height of the column, *A B*, is, on an average, not far from 30 inches, or 2½ feet.

If we suppose the cross-section of the tube to be one square inch, the atmospheric pressure upon that surface must be sufficient to balance the weight of 30 cubic inches of mercury. Now the weight of 30 cubic inches of mercury is a little less than 15 pounds; hence, we say the measure of the atmospheric pressure is 15 pounds on each square inch.

A pressure of fifteen pounds on each square inch is often called *an atmosphere*, and this becomes a unit for expressing the pressures of gases and vapors. Thus, when we say, in any given case, that the pressure of steam in a boiler is four atmospheres, we mean that it exerts a pressure of sixty pounds on each square inch of surface.

170. Pascal's Experiments. — As soon as TORRICELLI'S experiment was known in France, BLAISE PASCAL undertook to ascertain by experiment whether the mercury was actually retained in the tube by the pressure of the atmosphere, or by some other cause.

He caused a friend to repeat TORRICELLI'S experiment upon the top of the mountain of Puy-de-Dome, correctly reasoning that, if the height of the mercurial column is due to atmospheric pressure alone, it ought not to be so great on the mountain top as at the level of the sea. The result of the experiment showed that the height of the column was less on the top of the mountain than at its base.

He next reasoned, that if the tube were filled with any liquid less dense than mercury, the height of the column ought to be proportionally greater. Consequently, he made at Rouen, in 1646, the following experiment. He took a tube, similar to that of TORRICELLI, but nearly fifty feet in length, and after filling it with wine, inverted it in a vessel of the same liquid.

PASCAL observed that the column fell until it was about thirty-five feet high, when it came to rest. In this case the column was fourteen times as high as when mercury was used, and as mercury is fourteen times as dense as wine, he

concluded that the sole cause of the phenomenon in question was the pressure of the atmosphere.

171. The Barometer. — A **Barometer** is an instrument for measuring the pressure of the air. If to Torricelli's tube were fitted a scale for measuring the exact altitude of the mercurial column, it would be a barometer.

120.

Several forms have been given to the barometer, some of which will be described in the following articles.

172. The Cistern Barometer. — Fig. 120 represents a **Cistern Barometer**, such as is in common use in France and in this country.

It consists of a glass tube, *a i*, about 34 inches long, closed at the top and open at the bottom. This tube has a diameter of about four tenths of an inch. It is filled with mercury and inverted in a cistern, *A*, which is partially filled with the same liquid, as explained in Art. 165. The mercury settles in the tube till the height of the column is about 30 inches at the level of the sea.

The cistern, *A*, is 3 or 4 inches in diameter, and it is so adapted to the tube *a i*, as to permit the air to penetrate to the cistern at the joint *i*. Only a part of the cistern is seen in the figure, the remainder being let into the frame which supports the whole instrument. At the top of the frame is a scale, *c*, having its 0 point at the level of the mercury in the cistern; or, on the opposite side, is a scale on which are marked certain weather indications.

A curved piece of metal embraces the tube and carries an index, which, as the piece is raised to correspond to the top of the column, points out upon the height of the column. Two thermometers, one of one of alcohol, are also attached to the frame, which

serve to show the temperature of the instrument and of the mercury which it contains.

The 0 point, or beginning of the scale, is at the surface of the mercury in the cistern. When the pressure of the air increases, a portion of the mercury in the cistern is forced up into the tube, and the 0 point descends; when the pressure diminishes, the reverse takes place. But inasmuch as the surface of the mercury in the cistern is very great in comparison with that in the tube, this rise and fall is, for most purposes, quite unimportant. When great accuracy is required, the bottom of the cistern is made of leather, and can, by means of a screw, be raised or depressed until the surface of the mercury in the cistern just grazes the point of an ivory pin projecting from the top of the cistern. This improvement, devised by FORTIN, is now in general use.

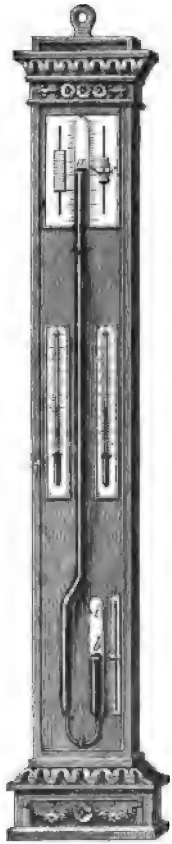


Fig. 121.

To determine the height of the barometer, the 0 point is first adjusted, then the curved piece is slid up or down till it coincides with the surface of the mercury in the tube, and the height is then read off on the scale *c*. The height of the thermometer should also be noted.

In the instrument described, the scale *c* does not extend throughout the whole length of the instrument, because, in ordinary cases, only a small part of the scale is needed. When a barometer is to be used in high altitudes, the scale is continued downwards as far as necessary.

173. The Siphon Barometer. — Fig. 121 represents a SIPHON BAROMETER. It consists of a curved tube, *a b*, having two unequal branches, the shorter one acting as a cistern. In the longer branch, there is a vacuum above the mercury, but the shorter one is supplied with air, which communicates with the external atmosphere through a small opening, *i*. There are two scales, one at the upper part of

each branch, and in front of each is a movable index, which may be raised or depressed until it comes to the free surface of the mercury in each branch. By means of these scales the difference of level in the two branches may be measured. This difference is the height of the barometric column.

To prevent violent oscillations when the instrument is moved from place to place, the two branches communicate through a fine, almost capillary tube. This arrangement also prevents the possibility of a bubble of air penetrating from the shorter to the longer branch, when the instrument is inclined.

Fig. 122.

174. The Wheel Barometer.

— This is a form of the Siphon Barometer in which the rise and fall of the mercury are shown by the movements of an index around a graduated circle. The manner in which it acts is shown in Fig. 122.

The index is attached to an axis which bears a pulley. Passing over this pulley is a fine wire, at one end of which is attached an iron weight, *a*, which rises when the height of the mercury diminishes, and falls when this height increases. At the second extremity is a counterpoise, *b*, which keeps the wire tense, and causes the wheel to turn as the weights rise and fall.

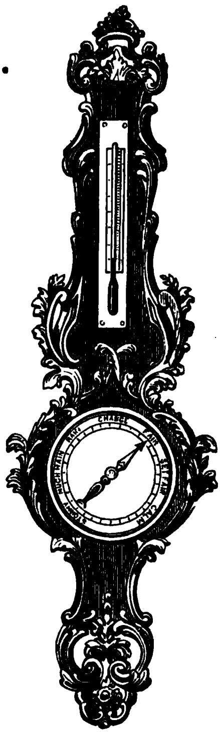


Fig. 123.

Fig. 123 shows its external appearance with a thermometer attached.

It will be seen that a slight change in the level of the mercury in the tube will produce a considerable movement of the index.

Notwithstanding this advantage, this form of barometer is of little value when accurate observation is required. The iron weight, *a*,

is somewhat heavier than the counterpoise, *b*, and thus there is a slight force in addition to the pressure of the air, which acts to sustain the column of mercury. Again, when the mercury in the shorter branch tends to rise, it must overcome the excess of weight in *a*, and consequently very minute changes of pressure are not recorded by this instrument.

175. The Aneroid Barometer. — The action of this curious instrument depends upon the effect produced by atmospheric pressure upon a metallic box from which the air has been partially exhausted. Its appearance and construction are shown in Fig. 124.

Fig. 124.

An increased atmospheric pressure tends to force the cover inward; but when the atmospheric pressure diminishes it is pressed outward by its own elastic force, aided by a spring in the interior. The movements of the cover, transmitted by a combination of delicate levers, cause an index to move over a graduated scale.

Being very easily portable, this form of barometer has lately come into extensive use, especially for measuring the heights of mountains.

Instruments of this kind are now made that may be carried in the pocket like a watch, and they are so sensitive to slight changes of pressure that they will indicate a change of level of not more than three or four feet.

176. Causes of Barometric Fluctuations. — Since the mercury in the barometer is sustained by the weight of the column of air above it, changes in the weight of this column of air will produce changes in the height of the mercurial column. Such changes are constantly going on, and consequently the barometer is continually fluctuating.*

* The atmosphere surrounds the earth like an immense ocean, nearly fifty miles in depth. It is never at rest, but has its great currents and tides; and, like the ocean of water beneath, it is agitated by storms, and

Certain very slight changes occur regularly; thus, there is a daily variation by which the mercury stands highest at ten o'clock morning and evening, and lowest at four o'clock afternoon and morning. These changes are greatest at the equator, where the variation is about one tenth of an inch. In latitude 40° it is 0.05 inch, and in lat. 70° only 0.003 inch.

There is also an annual inequality dependent on the seasons. In this country it is scarcely perceptible, but in China, and throughout a large part of Asia, the average height of the mercury is three fourths of an inch greater in January than in July.

The greater changes in the weight of the atmosphere are not periodical, but depend upon changes of temperature. When the temperature at any place is elevated, the air expands and rises until its lateral tension is greater than that of the surrounding air, when it flows away to the neighboring regions. When, on the contrary, the temperature is diminished, the air contracts and an additional quantity flows in from the neighboring regions.

The barometer, then, falls where there is a dilatation, and rises where there is a contraction of the air.

177. The Barometer as a Weather-Indicator.—The barometer is often called a weather-glass, and the scale of the instrument is sometimes inscribed with words intended to indicate the weather that may be expected when the top of the column stands opposite them. This, however, conveys an incorrect notion, for a change in weather is not indicated by the *absolute* height of the mercury at any given time.

Moreover, there are other conditions besides the weight of the atmosphere, which are quite as important as this, for the prediction of the weather. The temperature, the amount of moisture in the atmosphere, and the force and direction of the wind, are all to be considered as elements of the problem.

It is true, however, that changes in the heat, the moisture,

moves in immense waves. When the crest of one of these waves is over the barometer the mercury rises, and it falls again as the depression follows the crest of the waves.

or the movements of the air, are almost always accompanied, or immediately followed, by changes in the height of the barometer. Hence the *changes* in the height of the mercurial column may, to a certain extent, be relied on for predicting the weather. The following rules are generally reliable: —

1. The rising of the mercury indicates the approach of fair weather; the falling of the mercury shows the approach of foul weather.

2. A great and sudden fall of the mercury precedes a violent storm of short duration.

3. If, during fair weather, the mercury falls continually for several days, a long succession of foul weather will probably follow; and, again, if during foul weather which continues for a long time, the mercury gradually rises, fair weather may be expected to follow and continue for several days.

4. A fluctuating and unsettled state in the mercurial column indicates unsettled weather.

178. Measure of Mountain Heights. — One of the most important applications of the barometer is to the measurement of the height of any place above the level of the sea.

As we ascend above the level of the sea, the pressure of the air diminishes, and the barometer falls. Formulas have been deduced, by means of which the difference of level between any two places can be found, when we have the heights of the mercurial columns at the two places, together with the temperatures of the air and mercury at these places.*

* The exact rule for finding the height of a mountain by this method is rather complicated. Allowance must be made for temperature and for the latitude of each station; and other minor corrections are to be made. The following rule is given by Todhunter as nearly accurate for heights of not more than 3000 feet: —

Observe the height of the barometer at the bottom and at the top of the mountain; divide the difference of the heights by their sum, and multiply the result by 52,428; this will give the height of the mountain in feet.

The above rule assumes that the temperature at each station is 32° Fahrenheit. The result is made more accurate by adding a *thousandth part* for every degree in the sum of the temperatures above 64°. Thus, if the temperature at the lower station is 60°, and at the higher 45°, the sum is 105°, which exceeds 64° by 41°. Therefore the result obtained by the rule should be increased by the $\frac{41}{1000}$ part of itself.

The following table shows the height of the barometer at different altitudes where observations have been made: —

	Height above Sea-level.	Mean Height of Barometer.
	Feet.	*Inches.*
Level of the Ocean	0	30.00
Summit of Vesuvius	3,937	25.98
Summit of Mt. Washington, N. H. . .	6,288	
City of Quito, South America. . . .	9,541	21.02
Summit of Mont Blanc	15,748	16.69
On the Chimborazo	20,014	14.17
Highest Ascent in a Balloon (Glaisher)	37,000	7.00

179. Pressure on the Human Body. — The pressure on each square inch of the body is fifteen pounds; hence, on the whole body the pressure is enormous. If we take the surface of the human body equal to 2000 square inches, which is not far from the average in the case of an adult, the pressure amounts to 30,000 pounds, or fifteen tons.

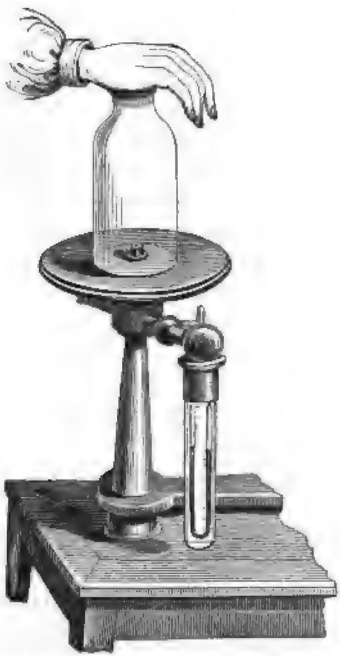


Fig. 125.

If it be asked why the body is not crushed by this enormous pressure, the answer is, because it is uniformly distributed over the whole surface, and is resisted by the elastic force of air, and other gases, distributed through the tissues of the body.

The following experiment will show that the tissues of the human

body contain air and gases, whose elasticity resists the atmospheric pressure. Let the hand be pressed closely upon the mouth of a glass cylinder, whose interior communicates with the air-pump, as shown in Fig. 125. No inconvenience will be felt. But if the air be exhausted from the cylinder, the flesh of the hand will be forced into the cylinder by the pressure from without, which is no longer resisted by the pressure of the air. The hand swells, and the blood tends to flow out through the pores.

The question may be asked, why, when the hand is placed upon a body, it is not retained there by the pressure of the atmosphere. The answer is, there is a thin layer of air between the hand and the body, which exactly counterbalances the effect of the external pressure. Were the air perfectly excluded from between the hand and the body, there would be a strong tendency to adherence between them.

The operation of cupping, in medicine, depends upon the principle just explained.

Summary. —

Properties of Gases and Vapors.
- Tension.
- Reduction to Liquids.

The Atmosphere.
- Physical Properties.
- Chemical Composition.
- Expansive Force.
  - Experiment.
- Weight.
  - Experiment.

Atmospheric Pressure.
- Experiments.
- Magdeburg Hemispheres.
- Upward Pressure.
  - Experiments.
- Torricellian Tube.
- Pascal's Experiments.

The Barometer.
- The Cistern Barometer.
- The Siphon Barometer.

SECTION II. — MEASURE OF THE ELASTIC FORCE OF GASES.

180. Mariotte's Law. — When a given mass of any gas or vapor is compressed, so as to occupy a smaller space, its elastic force is increased; on the contrary, when the volume is increased, its elastic force is diminished.

The law of increase and diminution of elastic force was first made known by MARIOTTE; hence it was called by his name. MARIOTTE's Law may be enunciated as follows: —

The elastic force of any given amount of gas, whose temperature remains the same, varies inversely as its volume.

As a consequence of this law it follows that,

If the temperature remains constant, the elastic force varies as the density.

181. Mariotte's Tube. — MARIOTTE's Law may be verified by means of an apparatus, shown in Figs. 126 and 127, called *Mariotte's Tube.* This tube is of glass, bent into the shape of a letter J. The short branch is closed, and the long one open at the top. The tube is attached to a wooden frame, provided with suitable scales for measuring the heights of mercury and air in the two branches.

The instrument having been placed vertical, a sufficient quantity of mercury is poured into the long branch to cut off communication between the two branches, as shown in Fig. 121. The level of the mercury in the two branches is the same, and this level is at the 0 point of the two scales. The air in the short branch is of the same

density, and has the same tension, as that of the external atmosphere.

If an additional quantity of mercury be poured into the longer branch of the tube, it will press upon the air in the shorter branch,

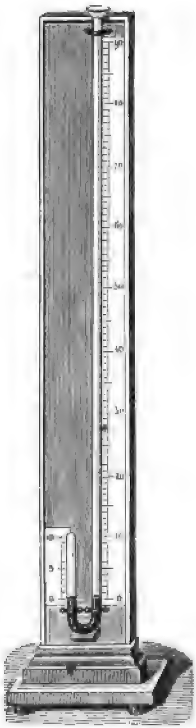


Fig. 126.

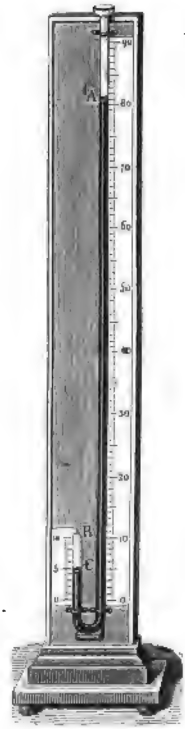


Fig. 127.

and compress it. If the difference of level in the two branches be made equal to the height of the barometrical column, as shown in Fig. 127 (where the difference is 76 centimeters, or 29.92 inches), the air will be compressed into $B\ C$, one half of its original bulk.

SECTION III. — PUMPS AND OTHER MACHINES.

182. The Air-Pump. — This machine was invented by Otto von Guericke in 1650.

Many improvements have since been made in its construction, but the essential parts remain the same as in the original invention.

Fig. 128 represents the essential parts of one of the best modern forms. It consists of a glass or metal cylinder called the barrel, in which a piston works. The piston has an opening through it which is closed by a valve, *S*, opening upwards.

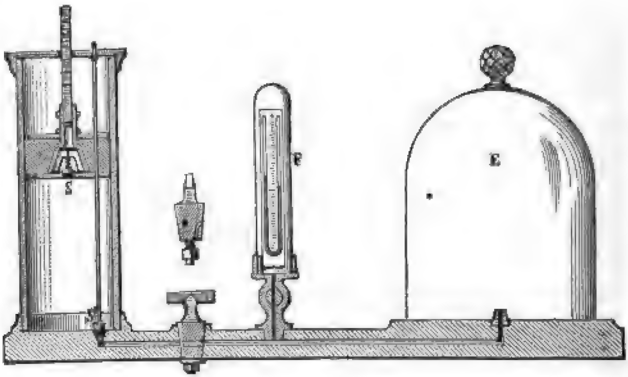


Fig. 128.

The barrel is connected by a tube with the centre of a brass plate, to which the receiver, *E*, is carefully fitted so as to be air-tight. The entrance to this tube is fitted with a conical valve, *S′*, at the end of a metal rod which passes through the piston head, and works in it tightly, so as to be carried up and down with the motion of the piston. This rod is so arranged by a catch at the top that it can lift the valve but slightly above the opening.

The following is its mode of operation: —

Suppose the piston to be at the bottom of the cylinder. Then, when it is raised, the valve, *S′*, is opened, and the air from the receiver, *E*, rushes into the cylinder. When the piston is lowered

again, the valve, S', closes; the air which has entered the cylinder cannot return into the receiver, and, on being compressed, raises the valve, S, in the piston and escapes into the air outside.

On raising the piston again, another portion of air will pass from the receiver into the cylinder, and this will be removed, as before, when the piston is lowered again.

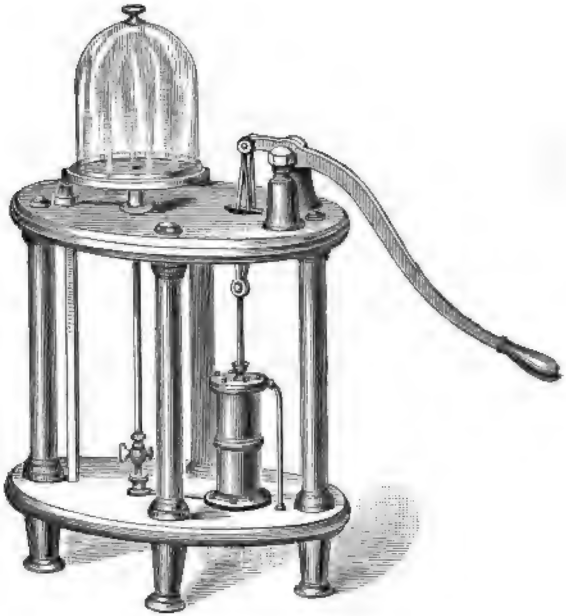


Fig. 129.

If this motion is continued, a portion of the air in the receiver will be removed at each successive stroke; and, finally, nearly all the air may be exhausted from the receiver.

The vacuum produced in this way can never be perfect, however, for the process of exhaustion can continue only so long as the air remaining in the receiver has elastic force enough to expand and flow through the pipe to fill the cylinder, when the piston is raised.

Fig. 129 represents one of the best of the simple forms of the instrument, as made by E. S. Ritchie, of Boston.

183. The Mercurial Gauge.—In order to measure the degree of rarefaction produced, a glass cylinder, *F* (Fig. 128), is connected with the pipe leading from the receiver. In this cylinder is a glass tube bent into the form of the letter U, one branch being closed at the top, and the other open. The tube has its closed branch filled with mercury, and is called a *siphon gauge.*

The mercury, under ordinary circumstances, is kept in the closed branch by the atmospheric pressure, but as the air becomes rarefied in the receiver, the tension of the air becomes less and less, and finally the mercury falls in the closed branch and rises in the open one. The difference of level between the mercury in the two branches is due to the tension of the rarefied air, and if this difference is determined by means of a proper scale attached to the gauge, the tension can be found. Thus, if the difference of level is reduced to one inch, the tension of the air in the receiver will be only one-thirtieth part of the tension of the external atmosphere.

The siphon gauge is sometimes connected with the receiver in a different way; as seen in Fig. 113 and 125. It is only necessary that it should be so placed that the air will be exhausted from it at the same time, and to the same degree as from the receiver.

184. Sprengel's Air-Pump.—Various methods have been employed for obtaining a more complete vacuum than can be produced by the ordinary air-pump. One of the most effective instruments for this purpose is *Sprengel's Air-Pump*, represented in Fig. 130.

To the funnel, *A*, is attached a glass tube, longer than a barometer tube. Its lower end enters the glass vessel, *B*, and reaches nearly to the bottom. The upper part of the tube branches off at *x*, and is connected with the receiver that is to be exhausted.

Mercury is poured into the funnel, *A*, and as it flows down the tube, air from the receiver enters at *x*, and is carried along with it. The tube below is then seen to be filled with cylinders of mercury separated by cylinders of air, all moving downwards.

The mercury in the bottom of the vessel, *B*, prevents the air from passing back into the tube, and it escapes while the mercury flows into the vessel, *H*.

As the process goes on, the cylinders are seen to be separated by smaller and smaller spaces of air, till it apparently passes down as a solid column, no air spaces appearing. This indicates the completion of the process.

The only labor required is that of lifting and pouring the mercury back into the funnel after it flows out.

The operation is very slow, but it produces a vacuum so nearly perfect that less than one-millionth part of the original quantity of air remains in the receiver.

By employing tubes of sufficient length water can be used instead of mercury.

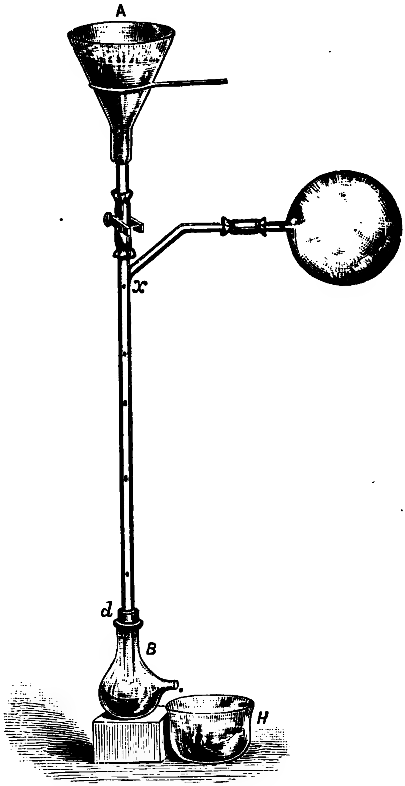


Fig. 130.

The *filter-pumps*, now much used in chemical laboratories, are constructed on the same principle.

185. Experiments with the Air-Pump. — Several experiments requiring the use of the air-pump have already been described. Most of these serve to show the pressure of the

atmosphere. Fig. 131 shows the elastic force of a confined body of air.

Two bottles, *A* and *B*, are connected by a tube which is fitted air-tight into *A*, but loosely into *B*. The tube extends nearly to the bottom of *A*, which is partly filled with water. When both are placed under the receiver, and the air exhausted, the elastic force of the air in *A* causes it to expand and drive the water over into *B*.

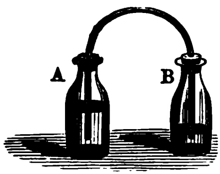


Fig. 131.

If a lighted candle be placed under a receiver, and the air exhausted, the candle will go out and the smoke will sink, showing that it is heavier than the rarefied air of the receiver.

If an animal or bird be placed under the receiver, and the air exhausted, it will struggle and soon die. This experiment is shown in Fig. 132.

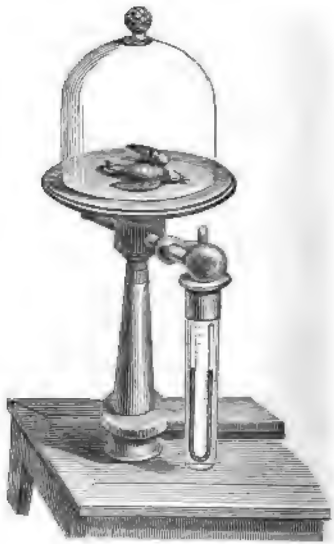


Fig. 132.

186. Practical Uses of the Air-Pump. — The most important practical application of the air-pump is in diminishing the pressure of the atmosphere to facilitate evaporation of liquids.

In order to concentrate the syrup of sugar without employing a high degree of heat, it is placed in closed vessels called *vacuum pans*, and the air and the steam that rise are removed by powerful air-pumps driven by steam-power. By this method the watery vapor is rapidly carried off, and the syrup brought to the proper degree of concentration without employing a degree of heat that would burn or discolor the syrup.

The same process is employed in making or concentrating a great variety of syrups and extracts that are used in medicine.

The air-pump has also been employed for exhausting long tubes that are used for transmitting letters, messages, and various small packages. These are called *Pneumatic Tubes*.

In London, where these tubes are extensively used, they are made of lead enclosed in tubes of iron. They are made smooth on the inside, and fitted with pistons consisting of cylinders of gutta-percha, in which the articles to be transmitted are placed. The air is then exhausted, and the pressure of the atmosphere drives the piston through the whole length of the tube. The tubes used for this purpose are about 2½ inches in diameter; and some of them are more than two miles in length.

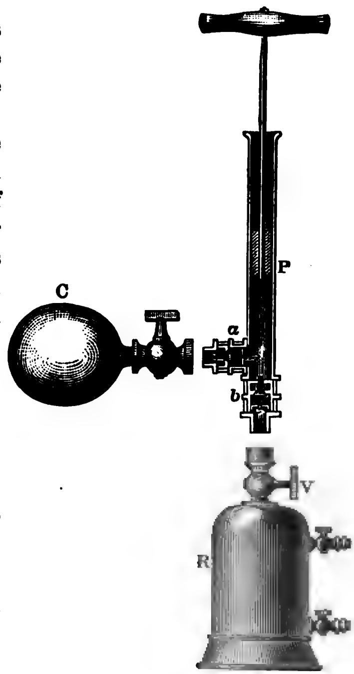


Fig. 133.

187. The Condenser.— This machine is simply an air-pump with the valves reversed. It is used for compressing air and forcing it into a small space. Fig. 133 shows the construction of one of the common forms. At the bottom of the pump-barrel there is a valve, *b*, which opens downward; at *a*, in a lateral tube, is an admission valve which opens inward. *R* is a strong copper vessel, which is screwed upon the lower part of the pump-barrel.

When the piston is forced downward the air enters the receiver through the valve, *b*, which prevents its return. At the upward stroke the air enters the cylinder, through *a*. As the movement

Fig. 134.

goes on, successive portions of air are drawn through *a*, and forced through the valve, *b*, into the receiver. If another closed vessel, at *C*, be connected with the lateral tube at *a*, it will be exhausted of air by the same process. Hence this instrument may be used to transfer gases from one vessel to another.

188. Applications of Condensed Air.—In the improved method of transmitting messages by pneumatic tubes, condensers as well as air-pumps are used; the air being forced into the tubes behind the pistons at the same time that it is exhausted in front.

In laying the foundations of bridges, and in various submarine operations, air is forced into large tubes, open at the bottom, which are sunk in the water where work is to be done. These tubes are so arranged that men can enter them and work at the bottom while the water is kept out by the pressure of condensed air.

It is possible for men to remain for a considerable time, without injury, in an atmosphere of three or four times the ordinary density; the only inconvenience being a painful sense of oppression in the ears. This feeling takes place only at the beginning and end of the operations, disappearing when an equilibrium is established between the tension of the air in the internal ear and that without.

189. Application to Tunnelling and Mining.—One of the most important uses of compressed air has been in the boring of tunnels through mountains of solid rock.

The excavation of the Mont Cenis Tunnel in the Alps, and of the Hoosac Tunnel in Massachusetts, was accomplished by means of machines driven by compressed air.

At the Hoosac Tunnel, the water-power of the Deerfield River, which flows near the eastern entrance, was used to operate several powerful compression-pumps, which forced the condensed air through an iron pipe to the point of working in the tunnel.

Here it was made to drive a number of drilling-machines, by which the rock was perforated. The machines consisted

essentially of cylinders fitted with pistons, to which the drills were attached. Eight or ten of these machines were fastened to a heavy iron framework resting on wheels, by which it could be moved forward and back, on rails laid for the purpose (Fig. 134).

When in use, this framework was brought up and firmly fastened near the "heading" to be operated on. The drilling-machines were

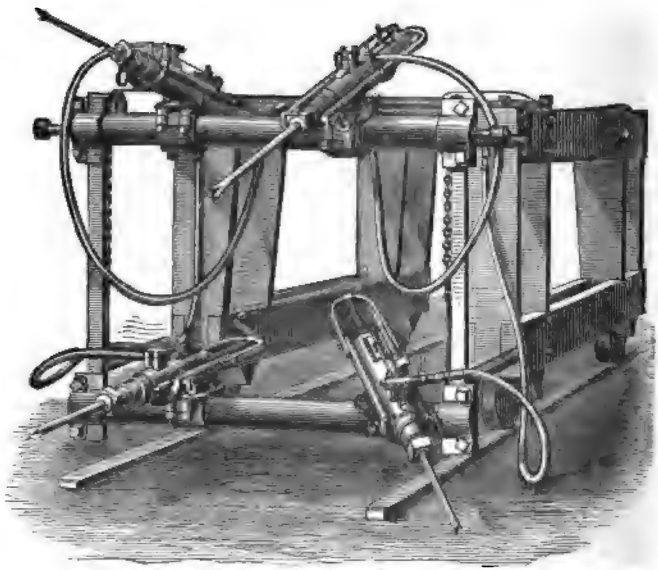


Fig. 135.

then fixed in the proper position on the framework, and the compressed air from the iron pipe was conducted to the several machines by smaller flexible tubes. Here it was admitted to the cylinders, alternately before and behind the pistons which carried the drills, driving them with great force and rapidity against the rock.

Fig. 135 represents the iron framework, or carriage, with four drills attached. The flexible tubes shown in the figure carry the air to the machines from the iron pipe laid along the bottom of the tunnel.

Fig. 136 represents a form of the drilling-machine which is now extensively used in mining operations. It is mounted upon a column, on which it may be raised or lowered by means of the screw-thread cut upon its surface. It is also arranged so that the drill may be driven in any direction required.

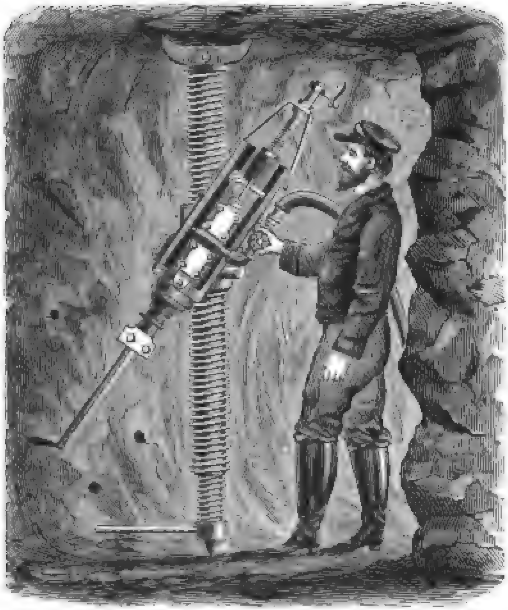


Fig. 136.

190. Advantages in the Use of Compressed Air. — For work in tunnels, deep mines, and other confined spaces, there are several advantages in the use of compressed air: —

1. The power may be transmitted through a great distance with very slight loss.

At the Hoosac Tunnel, when the work was done at a distance of nearly three miles from the compressors, the loss of power was less than four per cent of the whole.

2. The air, after doing its work in the machines, escapes and serves as a fresh supply of pure air, and drives out the

smoke and the noxious gases which would otherwise accumulate from the blasting, the burning of lamps, and the breathing of the workmen.

3. In deep mines, where the heat is often oppressive, the expansion of the air, as it escapes, lowers the temperature.

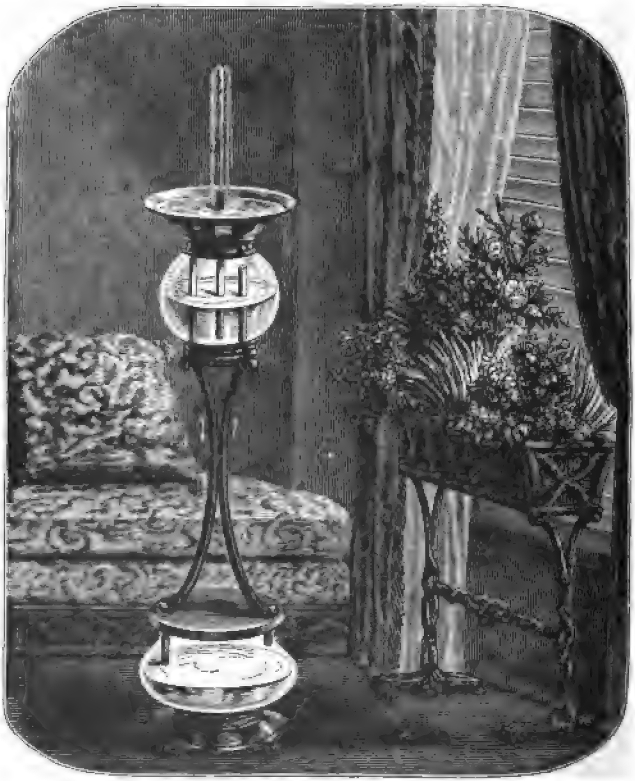


Fig. 137.

191. Artificial Fountains.—Water may be forced upward, in the form of a jet, by the tension of compressed air. Hero's Fountain, one form of which is shown in Fig. 137, is operated in this way.

It consists of two globes of glass, connected by two metallic tubes. The upper globe is surmounted by a brass basin, connected with the globe by tubes, as shown in the figure.

To use the instrument, the tube which forms the jet is withdrawn, and through the opening thus made, the upper globe is nearly filled with water, the lower one containing air only. The jet tube is then replaced, and some water is poured into the basin.

The water in the basin, acting by its weight, flows into the lower globe, through the tube shown on the left of the figure, as indicated by the arrow-head. This flow of water into the lower globe forces out a part of the air in it, which, ascending by the tube shown on the right of the figure, accumulates in the upper globe. The pressure of the air in the upper globe, acting upon the water in that part of the instrument, forces a part of it up through the *jet tube*, giving rise to a jet of water, which may be made to play for several hours without refilling the instrument.

192. The Atmospheric Inkstand. — This form of inkstand now in common use illustrates the principles of atmospheric pressure.

It is represented partially filled with ink in Fig. 138. The body of the inkstand is air-tight. Near the bottom is a tube for supplying the ink as wanted, and also for filling the inkstand when necessary. It is filled by turning it until the tube is at the top, when the ink can be poured in through the tube. The pressure of the atmosphere prevents the ink from flowing out. When the ink has been used till its level falls below *o*, where the tube joins the main body of the inkstand, a bubble of air enters, and rising to the top, acts by its pressure to fill the tube again, and so on until the ink is exhausted.

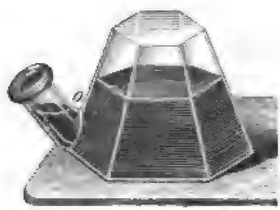


Fig. 138.

Summary. —

Measure of the Elastic Force of Gases.

Mariotte's Law.

Verification of the Law.

The Air-Pump.
Description of Leslie's.
Mode of Operation.
The Mercurial or Siphon Gauge.
Sprengel's Air-Pump.
Description.
Mode of Operation.
Experiments with the Air-Pump.
Practical Uses of the Air-Pump.
The Condenser.
Description.
Mode of Operation.
Applications of Condensed Air.
In laying the Foundations of Bridges.
In Submarine Work.
In Tunnelling and Mining.
Advantages of Compressed Air.
1. In transmitting Power at Great Distances with Slight Loss.
2. In driving out the Noxious Gases caused by Blasting, by means of Waste Air, and also in furnishing Pure Air.
3. In lowering the Temperature of the Mine.
Artificial Fountains.
Hero's Fountain.
Atmospheric Inkstand.

193. **Water-Pumps.** — A WATER-PUMP is a machine for raising water from a lower to a higher level, generally by the aid of atmospheric pressure. Three separate principles are employed in working pumps: the *sucking*, the *lifting*, and the *forcing* principles. Pumps are often named according as one or more of these principles are employed.

194. **The Lifting-Pump.** — The common lifting-pump acts upon the principle of atmospheric pressure. Its mode of operation may be understood from Figs. 139, 140, and 141,

which represent sections of the pump in different states of action. In all of the figures, *a* is the sleeping-valve, *c* the piston-valve, and *B* the sucking-pipe.

Suppose the piston to be at the lowest point of its play; there will then be an equilibrium between the pressure of the air within the pump and that without. When the piston is raised to the highest point of its play, the air beneath it is

Fig. 139.

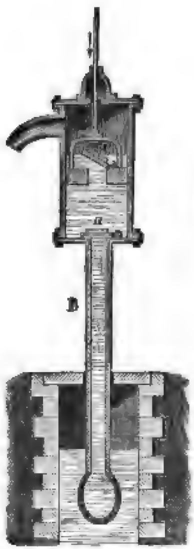


Fig. 140.

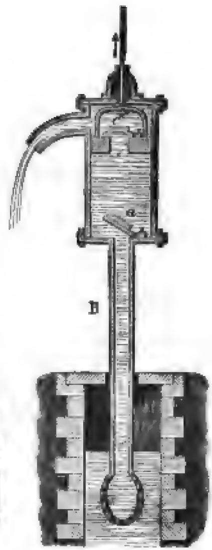


Fig. 141.

rarefied, and its tension diminished; the tension of the air in the sucking-pipe then forces up the sleeping-valve, and a portion of it escapes into the barrel. The tension of the air in the sucking-pipe being less than that of the external atmosphere, a quantity of water rises in the pipe, to restore the equilibrium. The water continues to rise till its weight, increased by the tension of the air in the pump, is just equal to the tension of the external air. When the equilibrium is restored, the sleeping-valve closes by its own weight.

Now, if the piston be depressed, the air in the barrel is condensed, forces open the piston-valve, and a portion escapes into the external atmosphere. If the piston be raised again, an additional quantity of water will be forced into the pump, and after one or two strokes of the piston, it will begin to flow into the barrel, as shown in Fig. 139.

When the water rises above the lowest limit of the play of the piston, the latter in its descent will act to compress the water in the barrel. This pressure forces open the piston-valve, and a portion of the water passes above the piston, as shown in Fig. 140. By continuing to elevate and depress the piston, the water will be raised higher and higher in the pump, till at length it will flow from the spout, as shown in Fig. 141.

As the water is raised in the pump by atmospheric pressure, it is necessary that the lowest limit of the play of the piston should not be more than 34 feet above the surface of the water in the reservoir, even at the level of the sea. To provide against barometric fluctuations and other contingencies, it is usual to make this distance considerably less than 34 feet.

195. The Forcing-Pump. — In the FORCING-PUMP the sucking-pipe may be dispensed with, and the barrel plunged directly into the reservoir, as shown in Figs. 142 and 143, or a sucking-pipe may be employed, as will be explained hereafter. We shall first consider the case in which the sucking-pipe is omitted.

In this case the piston is solid, and a lateral pipe, *H*, called the *delivery-pipe*, is introduced below the level of the lowest position of the piston. There are two valves, both fixed, the sleeping-valve, *a*, as in the sucking-pump, and a valve, *c*, opening into the delivery-pipe.

When the piston is raised to its highest position, as shown in Fig. 142, the pressure of the atmosphere on the water in the reservoir forces open the sleeping-valve, and the barrel is filled with water up to the bottom of the piston, when the sleeping-valve closes by its own weight. On depressing the piston, the valve, *c*, is forced open, and a portion of the water in the barrel is forced into the delivery-pipe. When the piston reaches its lowest position, the weight of the water in

the delivery pipe closes the valve, *c*, and prevents the water in the delivery-pipe from returning into the barrel.

By continually raising and depressing the piston, additional quantities of water are forced into the delivery-pipe, which finally escape from the spout at the top of the delivery-pipe, as shown in Fig. 143.

To regulate the flow of the water through the delivery-pipe, and to facilitate the working of the pump, an air-vessel is generally introduced, as will be explained in Art. 196. Sometimes the working

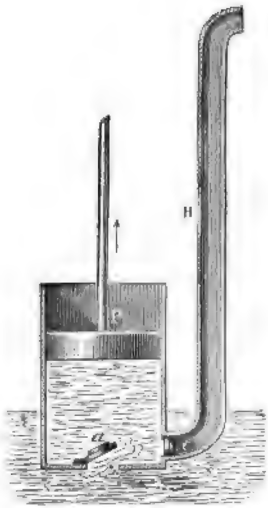


Fig. 142.

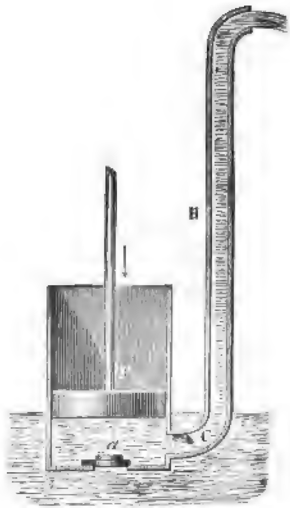


Fig. 143.

is rendered uniform by combining two forcing-pumps in such a manner that the piston of the one ascends whilst that of the other descends. This combination is explained in Art. 197.

196. The Forcing-Pump with Air-Chamber.—This differs from the simple forcing-pump, described in Art. 195, in having a sucking-pipe and an air-vessel. It consists of a barrel, *A*, a sucking-pipe, *B*, a sleeping-valve, *G*, and a solid piston, *C*, worked by a lever, *E*, and piston-rod, *D*. A pipe leads from the bottom of the barrel, through a sleeping-

valve, *F*, into an air-vessel, *K*. The delivery-pipe, *H*, enters the air-chamber at its top, and extends nearly to the bottom.

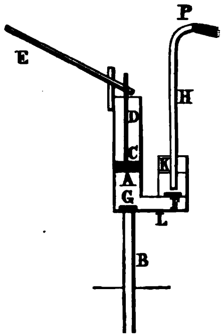


Fig. 144.

To explain the action of the pump, suppose it empty and the piston at its lowest position; when it is raised to its highest position, the air in the barrel is rarefied, the tension of the air in the sucking-pipe forces open the valve, *G*, and a portion of it escapes into the barrel; the water is then forced up the sucking-pipe by the tension of the external air acting on the surface of the water in the reservoir until an equilibrium is produced, when the valve, *G*, closes by its own weight.

If the piston be again depressed to its lowest limit, the air in the barrel is condensed until its tension exceeds that of the external air, when it forces open the valve, *F*, and a portion escapes into the air-vessel. After a few double strokes of the piston the water rises through the valve, *G*, and the action becomes the same as in the pump described in Art. 195, with the exception of the air-vessel, which serves to keep up a continuous stream through the delivery-pipe. The piston ought not to be more than 34 feet above the reservoir. The spout, *P*, may be at any height above *K*.

197. The Fire-Engine. — A FIRE-ENGINE is a double forcing-pump, having its delivery-pipe composed of leather or other flexible material. It is used, as its name implies, for extinguishing fires.

Fig. 145 shows a section of the essential parts of a fire-engine. In this figure, *P Q* is the lever to which are attached the piston-rods that move the pistons, *m* and *n*; *R* is an air-vessel with two valves, one admitting water from each barrel; *Z* is the entrance to the hose or delivery pipe; *M* and *N* are rods sustaining the framework of the machine.

The two barrels are plunged into a reservoir which is kept supplied with water. This water flows into a space beneath the barrels through holes represented on the right and left

of the figure, and from thence is forced into the air-vessel in a manner entirely similar to that explained in the the last article. When the water is forced into the air-vessel, *R*, the air is at first compressed, after which it acts by its tension to force a continuous current through the hose.

The lever is provided with long handles at right angles to its length, so that it may be worked by several men acting together.

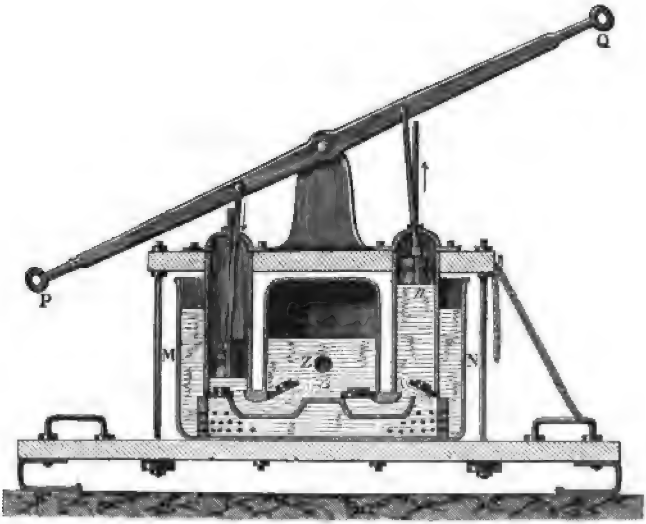


Fig. 145.

Within a few years many improvements have been introduced into the fire-engine, one of the most important being the application of steam as a motor.

198. The Siphon. — The SIPHON is a bent tube, by means of which a liquid may be transferred from one reservoir to another, over an intermediate elevation. The siphon may be used with advantage when it is required to draw off the upper portion of a liquid without disturbing the lower portion. This operation is called *decanting*.

The siphon consists of two branches of unequal lengths, as shown in Fig. 146. The shorter one is plunged into the liquid to be decanted, and the flow takes place from the longer one.

To use the siphon, it must first be filled with the liquid. This operation may be effected by applying the mouth to the outer end of the siphon, and exhausting the air by suction, or it may be inverted and filled by pouring in the liquid, and stopping both ends, after

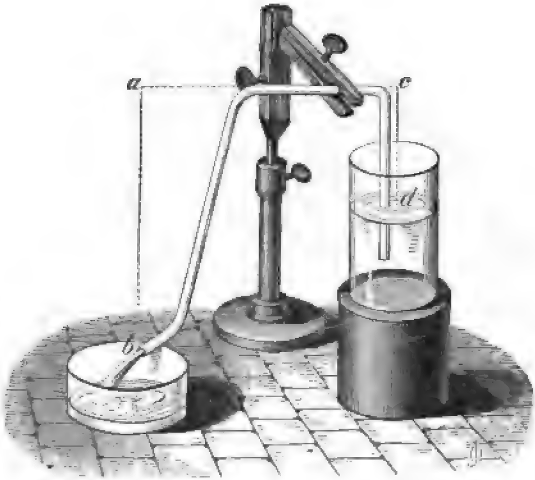


Fig. 146.

which it is again inverted, care being taken to open both ends at the same instant. Sometimes a sucking-pipe is employed to exhaust the air and fill the siphon.

When the flow commences, it will continue until the liquid in the first reservoir falls below the level of the end of the siphon.

To understand the action of the siphon, we must consider the forces called into play. The water is urged from d towards b, by the pressure of the atmosphere on the fluid in the reservoir, together with the weight of the water in the outer branch of the siphon; that is, by the weight of a column of water whose height is $a\,b$. This motion is retarded by

the pressure of the atmosphere at *b*, together with the weight of the fluid in the inner branch; that is, by the weight of a column whose height is *c d*. The difference of these forces is the weight of a column of the liquid whose height is the excess of *a b* over *c d*, and it is by the action of this force that the flow is kept up. The greater this difference the more rapid will be the flow, and the less this difference the slower the liquid will escape. When this difference becomes zero, the flow ceases altogether.

The siphon is used for conveying water over hills, but for this purpose the highest point of the tube should not be more than thirty feet above the level of the water in the reservoir, this being about the height at which the atmospheric pressure will sustain a column of water.

199. Adhesion of Liquids and Gases. — A rapid current or jet, either of a liquid or a gas, tends to carry along with it the surrounding particles of air which adhere to it, and thus to produce a partial vacuum. This principle is made use of in raising liquids through tubes. Let a powerful jet of steam be directed horizontally over the open end of a vertical tube, the lower end of which is plunged in water; the air from the tube is swept along by the steam, a vacuum is produced, the water rises, and is, in its turn, driven forward by the jet of steam.

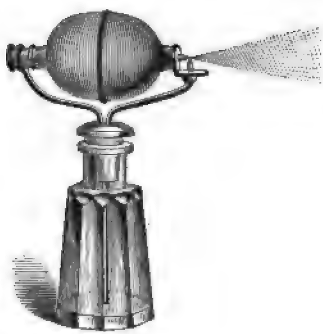


Fig 147.

In the apparatus known as Giffard's Injector, water is supplied to the boiler of a steam-engine by a jet of steam, which is thrown with great force through a small pipe into the centre of a larger tube connected with the supply of water. A vacuum being formed about the jet, water is drawn forward and thrown into the boiler.

The same principle is made use of for throwing a fine spray of

liquid into the air, as shown in Fig. 147. By pressing upon the rubber bulb a blast of air is made to issue from a jet, which is placed over the opening of a tube that extends into the liquid in the bottle. The force of the blast first exhausts the air, and then throws the liquid which rises from the tube in fine spray or mist.

Summary. —

Water-Pumps.
- Definition.
- Principles Employed.

Lifting-Pump.
- Principle Involved.
- Description.
- Mode of Operation.

Forcing-Pump.
- Description.
- Mode of Operation.
- With Air-vessel attached.

Fire-Engine.
- Description.
- Mode of Operation.

Siphon.
- Definition.
- Description.
- Mode of Operation.

Adhesion of Liquids and Gases.
- Principle Explained and Illustrated.
- Giffard's Injector.

SECTION IV. — APPLICATION TO BALLOONING.

200. Buoyant Effort of the Atmosphere. — It has been shown that a body plunged into a liquid is buoyed up by a force equal to the weight of the displaced liquid. That a similar effect is produced upon a body in the atmosphere, may be shown by means of an instrument called a *baroscope*, which is represented in Fig. 148.

The BAROSCOPE consists of a beam like that of a balance, from one extremity of which is suspended a hollow sphere of copper, and from the other extremity a solid sphere of lead. These are made to balance each other in the atmosphere.

If the instrument be then placed under the receiver of an air-pump and the air exhausted, the copper sphere will descend. This shows that in the air it was buoyed up by a force greater than that exerted upon the leaden sphere. If, now, the leaden sphere be increased by a weight equal to that of a volume of air of the same bulk as the copper sphere diminished by that of the leaden sphere, it will be found, after the air is exhausted, that the balance is in equilibrium. This shows that the buoyant effort is equal to the weight of air displaced. Hence we have the following principle, entirely analogous to the principle of ARCHIMEDES: —

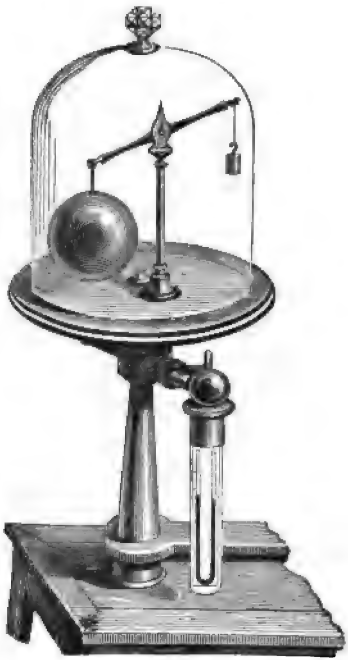


Fig. 148.

When a body is plunged into a gas, it is buoyed up by a force equal to the weight of the displaced gas.

If the buoyant effort is greater than the weight of the body, the latter will rise; if it is less, the body will fall; if the two are equal, the body will float in the atmosphere without either rising or falling.

Smoke, for example, rises, because it is lighter than the air which it displaces. It continues to rise until it reaches a stratum of air

where its weight is just equal to that of the displaced air, when it will come to rest and remain suspended. A soap-bubble filled with warm air floats for a considerable time in the atmosphere, being nearly of the same weight as the displaced air.

201. The Balloon.—A BALLOON is a spherical envelope filled with some gas lighter than air.

The first balloon made was filled with heated air and smoke, furnished by burning damp straw, paper, and the like, under the balloon, the lower part of which was left open to receive them. When filled, it rose to a height of more than a mile; but it soon became cooled, and fell to the earth. The use of hot-air balloons was, however, entirely given up on account of the serious accidents to which they were liable.

Small balloons of this kind, called fire-balloons, are often made for toys. A spherical bag of light paper is made, with a large opening at the bottom, across which are stretched wires; to these a sponge saturated with alcohol is fastened. The alcohol being set on fire, the air in the balloon becomes heated and rarefied till the whole is lighter than an equal bulk of the atmosphere, when it rises.

202. Balloons of the Present Day. — Balloons by which persons ascend are, at the present day, generally filled with hydrogen or coal gas. The latter, although heavier than the former, yet by reason of its cheapness, and the facility with which it can be procured, is usually preferred.

The envelope is made of silk, rendered air-tight by caoutchouc varnish on both sides of it. Sometimes two sheets of silk are used, with a sheet of india-rubber between them.

The basket, or car, made of wicker-work or whalebone, is suspended by means of cords to a network which completely covers the whole balloon or the entire upper half. This network is attached in such a manner as to distribute the weight of the car and its contents as evenly as possible.

At the top of the balloon is a valve kept closed by a spring; it can be opened by means of a string descending through the balloon to the car of the aeronaut. When he wishes to descend, he opens the valve, and allows a portion of the gas to escape. To ascertain whether he is ascending or descending, the aeronaut is provided with

a barometer; when ascending, the barometric column falls, and when descending, it rises. By means of the barometer, the height at any time may be determined.

A long flag fixed to the car will indicate, by the position it takes, either above or below, whether the balloon is rising or falling.

To enable the balloon to rise, it must displace a volume of air greater in weight than itself and all it carries. When the volume of air displaced is less in weight, the balloon will sink; when equal, it will, after a few oscillations, come to rest in that stratum of the atmosphere.

The measurements for a balloon of the ordinary dimensions, which can carry three persons, have been given as follows: 16 yards high, 12 yards in diameter, and, when it is quite full, about 680 cubic yards in volume. The balloon itself weighs 200 pounds; the accessories, such as the rope and car, 100 pounds.

Many attempts have been made to direct the course of balloons in the air, but so far all have failed. They present so extensive a surface, that the resistance of the air is sufficient to neutralize any efforts to propel them in any desired direction, with a degree of speed worth attaining.

203. Method of filling a Balloon and making an Ascent. — The balloon is filled by raising it three or four feet above the ground by pulleys, when the gas is introduced by means of a pipe or hose which connects with a gasometer. As the balloon fills with gas it is held down by ropes, and when nearly filled, the car is attached. Care should be taken not to fill the balloon completely, as the gas expands in rising, and unless an allowance is made for this expansion the balloon might be ruptured.

To regulate the ascensional power, the car is ballasted by sand, contained in small bags. Everything being ready, the ropes are detached, and the balloon ascends with greater or less velocity, according to the ascensional force.

When the aeronaut finds that he does not ascend fast enough, he increases the ascensional force by emptying one or more of the sand-bags. In like manner, in descending, if the velocity is too great, or if the balloon tends to fall in a dangerous place, the weight of the balloon is diminished by emptying some of the sand-bags.

To render the descent less difficult, the aeronaut is provided with

an anchor or grapple, suspended from a rope, by means of which he can seize upon some terrestrial object when he comes near the earth. When the anchor is made fast, the aeronaut draws down the balloon by pulling upon the rope.

204. The Uses of Balloons. — Balloons have been used in war to some extent for making observations within the lines of an enemy, and also as a means of communication between parties besieged and those without the lines of the besiegers.

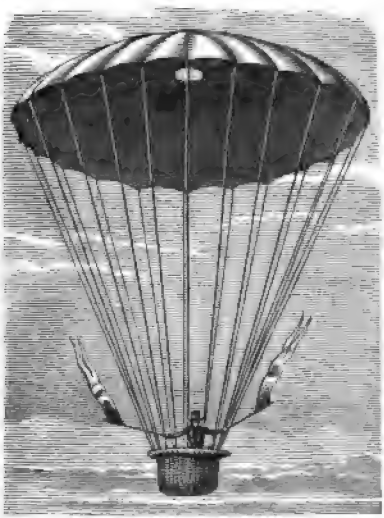


Fig. 149.

The most important use of the balloon, thus far, has been in making scientific observations in the higher regions of the atmosphere. Much valuable meteorological information has been gathered by the experiments in aerial navigation, especially by GLAISHER, an English aeronaut. The greatest height ever attained in a balloon was a little over seven miles, and was reached by GLAISHER on September 5, 1862.

205. The Parachute. — A PARACHUTE is an apparatus by means of which an aeronaut may abandon his balloon, and descend slowly to the earth.

The form and construction of a parachute, when detached from the balloon, are shown in Fig. 149.

It consists of a circular piece of cloth, 15 or 16 feet in diameter, presenting, when spread, the form of a huge umbrella. The ribs are made of cords, which, being continued, are attached to a wicker car, as shown in the figure.

A hole is made at the top, in the centre, which, by allowing a part of the compressed air to escape, directs the descent, and prevents violent oscillations, that might prove dangerous by the air escaping from under the edge of the parachute.

Mr. Wise, an American aeronaut, several times exploded his balloon, when high in the air, to show what he considered to be always the case, that the fragments with the network would, under such circumstances, form a parachute which would moderate the rate of descent, and allow the aeronaut to reach the earth in safety.

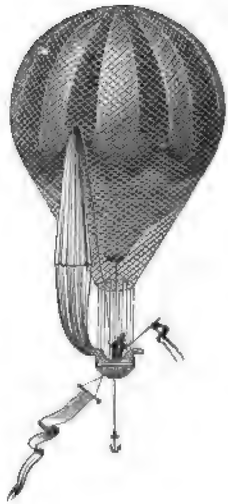


Fig. 150.

If from any cause it appears impracticable to effect a descent from the balloon itself, the parachute may be of the greatest service to the navigator. At present, however, it seems to be used to astonish the public by the skill and courage of the aeronaut, who dares to launch himself into space in this frail craft when no danger threatens his balloon.

All things considered, it is generally regarded as safe to effect a descent with the balloon as with the parachute.

In Fig. 150 is shown the balloon with parachute, attached to the network by means of a cord, which passes round a pulley, and is fixed at the other end to the car. When the cord is cut the parachute descends with great rapidity; but the air soon spreads the cloth, and then, acting by its resistance, the velocity is diminished, and the aeronaut reaches the ground without injury.

Summary.—

Buoyant Effort of the Atmosphere.

Baroscope.

Principle of Archimedes.

The Balloon.

Hot-air Balloon.

Toy Balloon.

The Balloon (continued).

Construction of Modern Balloons.

Mode of Navigation.

Principle that enables a Balloon to rise.

Measurements of a Balloon.

Directing the Course of a Balloon.

Method of filling a Balloon and preparing for its Ascent.

Valuable Information gained by Balloons.

The Parachute.

Use and Construction.

Experiment of Mr. Wise.

Exhibition of the Courage of the Aeronaut.

Illustration of the Method by which the Parachute is detached from the Balloon.

CHAPTER VI.

ACOUSTICS.

SECTION I. — PRODUCTION AND PROPAGATION OF SOUND.

206. Acoustics is that branch of Physics which treats of the laws of generation and propagation of sound.

207. Sound is a motion of matter capable of affecting the ear with a sensation peculiar to that organ.

Sound is caused by the vibration of some body, and is transmitted by successive vibrations to the ear. The original vibrating body is said to be *sonorous*. A body which transmits sound is called a *medium*. The principal medium of sound is the atmosphere; but all elastic bodies transmit sound, and are, therefore, *media*.

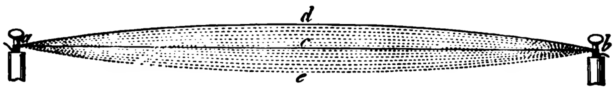


Fig. 151.

Let us take, for illustration, a stretched cord which is made to vibrate by a bow, as in a violin, for example. When the cord is drawn from its position of rest, *a c b* (Fig. 151), to the position, *a d b*, every point of the cord is drawn from its position of equilibrium; when it is let go, its elasticity causes it to spring back to its original position. In returning to this position, it does so with a velocity that carries it past *a c b* to *a e b*, from which it returns again nearly to *a d b*, and so on vibrating backward and forward, until, after a great number of oscillations, it at length comes to rest.

208. Sound-Waves in Air.—Mode of Propagation. —Sound-waves are produced in the air by the vibration of some sonorous body. When the body moves forward, it strikes the air in front of it, and condenses a stratum whose thickness depends on the rapidity of vibration; the particles of this stratum impart the condensation to those of the next, and these in turn to those of the next, and so on; the condensation thus transmitted outward is called the *condensed pulse*. When the body moves backward, the air in front of it follows, and produces rarefaction in a stratum whose thickness depends on the rapidity of vibration; this causes a backward movement and consequent rarefaction in the next stratum, which is transmitted to the next, and so on; the rarefaction thus propagated outward is called the *rarefied pulse*.

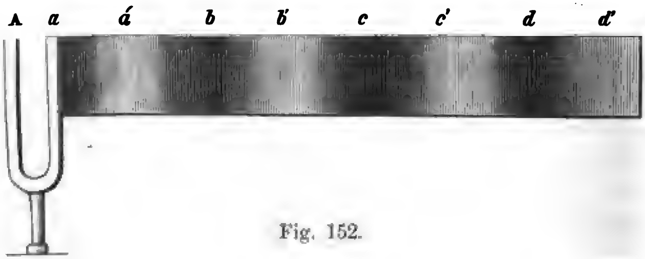


Fig. 152.

Fig. 152 illustrates the formation of sound-waves by the vibrations of a tuning-fork. The prong, *a*, as it springs outward, condenses the air in front, and then, receding, leaves behind it a partial vacuum. Thus each complete vibration generates a condensed and a rarefied pulse, and these together constitute a sound-wave. The dark spaces, *a*, *b*, *c*, *d*, represent the condensations, and the lighter spaces, *a′*, *b′*, *c′*, *d′*, the rarefactions; the wave-lengths are the distances *a b*, *b c*, *c d*.

When a bell is rung, the air around it is set in motion, and sound-waves are generated, which move outward in every direction in the form of spherical shells, as shown in Fig. 153.

The rate at which the sound-wave travels is the *velocity of sound;* the distance through which it travels in the time of one

vibration of the sonorous body is the *wave-length.* The form of the sound-wave is transmitted through the air, but the individual particles of air simply oscillate to and fro in the direction of wave propagation, moving forward on the passage of the condensed and backward on the passage of the rarefied pulse; the distance through which each particle oscillates is called the *amplitude of vibration* of the particle.

Any two particles situated on a line in the direction of propagation, and at a distance from each other equal to a wave-length, are always moving in the same direction and with equal velocities; such particles are said to be in the same *phase.* All the particles of any wave that are in the same phase are on the surface of a sphere, which is called a *wave-front.*

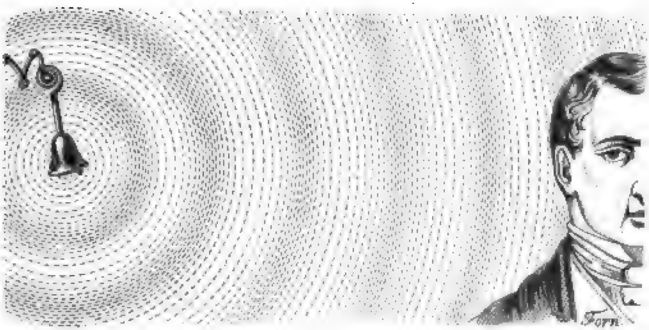


Fig. 153.

209. Combinations of Sound-Waves. — Many sounds may be transmitted through the air at the same time, and in some cases there is no perceptible interference of the sound-waves. In listening to a concert of instruments a practised ear can detect the particular sound of each instrument.

Sometimes, however, an intense sound covers up or drowns a more feeble one; thus, the sound of a drum might drown that of the human voice. Sometimes feeble sounds, which are too faint to be heard separately, by their union produce a sort of murmur. Such is the cause of the murmur of waves, the rustling sound of a breeze playing through the leaves of a forest, and the indistinct hum of a distant city.

210. Coincidence and Interference of Sound-Waves. — Two sets of sound-waves may coincide so as to increase the intensity of the sound, or they may interfere so as to neutralize each other and produce silence.

Suppose we have two tuning-forks, *A* and *B*, which produce waves of exactly the same length. Let them be placed a wave-length apart, as shown in Fig. 154. The two sets of vibrations

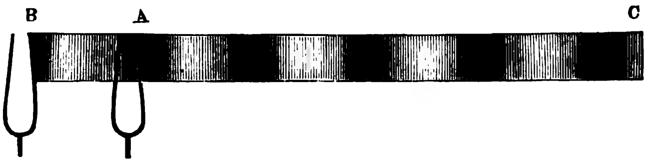


Fig. 154.

will coincide, and the intensity of the sound will be greater than if one were vibrating alone. The same would evidently occur if the distance between it and *B* were any number of whole wave-lengths.

But suppose *A* and *B* to be only half a wave-length apart. It is evident that the rarefactions of one of the systems of waves will then

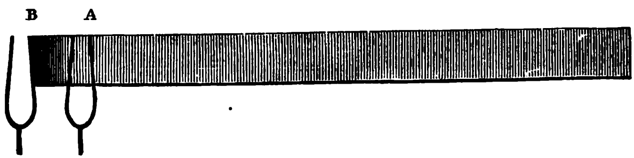


Fig. 155.

coincide with the condensations of the other system, and the result will be *interference*, by which both systems of waves will be destroyed. This result is indicated by the uniformity of shading in Fig. 155.

The interference of sound-waves can be shown by striking a small tuning-fork, and then holding it a short distance from the ear, rolling the stem at the same time between the thumb and finger. We shall find several positions where the sound-waves neutralize one another and no sound is heard, and also several where the waves coincide and there is a reinforcement of sound.

211. Beats.—When two tuning-forks which are not quite in unison are sounded together, there is no continuous sound produced, but a peculiar, palpitating effect, which is owing to a series of alternate reinforcements and diminutions of the sound. This succession of sounds with the intervals of comparative silence is known to musicians by the name of *beats*, and is the result of the coincidence and interference of the sound-waves.

Suppose one of the forks vibrates 100 times in a second, and the other 101 times. If the waves start at the same moment the condensations will coincide and also the rarefactions, but they begin to interfere more and more, inasmuch as one system has been gradually falling behind the other, until at the middle of the second it will have amounted to half a wave-length, and the two sounds will destroy each other.

At the end of the second, when one fork has completed its 100th vibration and the other its 101st, one system has fallen behind the other one wave-length, and there is coincidence again of crest and depression, and the full effect of both sounds reaches the ear. We have, then, one beat and one interval in every second.

In general, beats are produced by two musical sounds of nearly the same pitch emitted at the same time. *The number of beats per second is equal to the difference of the rates of vibration.*

Beats are frequently heard in the sound of church bells, and in the lower octaves of large organs. Telegraph wires, when made to vibrate by a strong wind, produce beats. These can be observed by pressing one ear against a telegraph-post and closing the other. If we strike simultaneously one of the lower white keys of a piano and the adjacent black key, beats will be heard.

Beats are of great value in tuning musical instruments. The notes given out by two musical instruments of slight difference in pitch can be brought into unison by tuning until the beats disappear.

212. Sound is not propagated in a Vacuum.—That some medium is necessary for the transmission of sound may be shown by the following experiment.

A bell is placed under the receiver of an air-pump, provided with a striking apparatus set in motion by clock-work. Before

the air is exhausted, the strokes of the hammer on the bell are distinctly heard, but as the air is exhausted the sound becomes fainter and fainter, till at last it ceases to be heard.

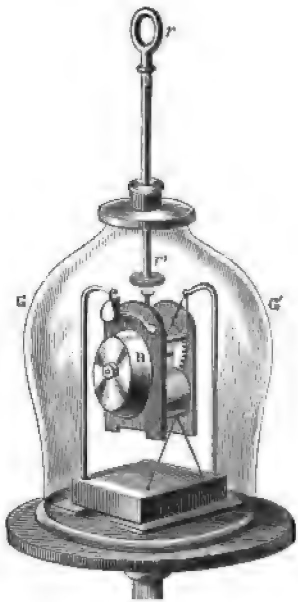


Fig. 156.

For the complete success of this experiment the bell and clock-work should be supported by some substance which does not readily transmit sound. As shown in Fig. 156, the apparatus is supported by silk threads. The sliding-rod, *r*, is used to set the clock-work in motion. If, after the air is exhausted, any vapor or gas is admitted, the sound is again heard; showing that other elastic fluids, as well as air, may transmit sound.

213. Propagation of Sound in Liquids and Solids.— Sound is transmitted, not only by gases, but also by liquids and solids. Divers hear sounds from the shore when under water, and sounds made under water are heard on shore. A slight sound made at one end of a long stick of timber is distinctly heard by an ear at the other end, even when it might be inaudible at an equal distance through the air.

The earth transmits sounds, and by placing the ear in contact with it, sounds may be distinguished at a great distance. This method of hearing approaching footsteps of men or animals is well understood by hunters. In the construction of subterranean galleries for mining purposes, the miner is often guided, as to the direction he should take, by sounds transmitted through large masses of earth and rock.

214. Velocity of Sound in the Air. — That sound occupies an appreciable time in passing from point to point

may be shown by many familiar examples. If we notice a man cutting wood at a distance, we perceive that his axe falls some time before the sound of the blow reaches the ear. If a gun is discharged, we see the flash before we hear the report. In like manner, the flash of lightning is seen before we hear the thunder.

In 1822 a number of scientific men undertook a series of very nice experiments to determine the velocity of sound. They placed a cannon on the hill of Montlery, near Paris, and another on a plain near Ville-Juif, the distance between them being 61,047 feet. At each station twelve discharges were made at intervals of ten minutes; the discharges alternating between the stations at intervals of five minutes. Observers placed at each station observed the intervals of time that elapsed between seeing the flash and hearing the report of the cannon at the other station. The average interval was 54.6 seconds, and the temperature was 61° F.; the actual velocity was found to be 1118 feet per second, which, after correcting for temperature, gave 1090 feet per second for the temperature 32° F.

It is shown by experiment that if the elasticity of the air be increased, the density remaining the same, the velocity of sound is increased; or, the elasticity remaining the same, if the density be decreased, the velocity is also increased. When our atmosphere is heated by the sun, its density is made less while its elasticity is not changed. The velocity of sound is found to increase thereby about one foot per second for each degree Fahrenheit.

The velocity of sound in air depends on the elasticity of the air *in relation to its density*. The greater the elasticity, the greater the velocity; the greater the density, the less the velocity. This can be expressed as follows: —

The velocity is directly proportional to the square root of the elasticity; it is inversely proportional to the square root of the density.

215. Velocity of Sound in Liquids. — Sound is transmitted more rapidly in liquids than in air. Its velocity in water was measured by Colladon and Sturm, in 1826, at

the Lake of Geneva, in Switzerland. Two boats were moored at a distance of nearly nine miles from each other. One of them supported a bell of about 140 pounds weight immersed in the lake. Its hammer was moved by a lever so arranged that, at the instant of striking the bell, it ignited a small quantity of gunpowder. An observer in the other boat heard the sound by means of a trumpet-shaped tube (Fig. 157), the lower end of which was covered with a membrane, and turned in the direction from which the sound came.

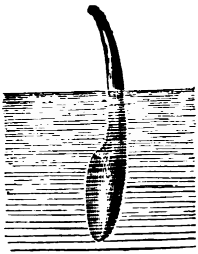


Fig. 157.

By observing the interval between seeing the flash and hearing the sound, the velocity was found to be about 4700 feet in a second, which is more than four times its velocity in air.

216. Velocity in Solids. — Solid bodies transmit sound more rapidly than gases or liquids. The velocity varies in different solids, and is greatest in dense and highly elastic bodies. Through steel wire sound moves at the rate of 15,470 feet per second; through silver, at 10,900 feet per second, — just ten times the velocity in air.

That sound travels faster in iron than in air may be shown by placing the ear at one extremity of a long iron bar or tube, while it is struck on the other end with a hammer. Two sounds will be heard, the first transmitted through the iron and the second through the air. The true reason that the velocity of sound in liquids and solids is greater than in air is found in the fact that their elasticities, when compared with their densities, are greater than that of air compared with *its* density.

217. Reflection of Sound. — Echoes. — When sound-waves in air strike upon a solid surface they are reflected, or thrown back; and, as in the case of elastic solid bodies, the angle of reflection is equal to the angle of incidence. A wave of sound falling perpendicularly on a wall or other flat sur-

face returns in the same direction to the spot from which it emanated, and produces there an *echo*.

A hard or perfectly smooth surface is not necessary to secure reflection of sound. It is reflected from cliffs, from wooded slopes of mountains, from the surface of water, and even from clouds, in such a way as to form distinct echoes. A sharp, quick sound may be returned as an echo from a distance of fifty-five feet, but, to repeat spoken words or syllables distinctly, the reflecting surface must be so far distant from the speaker as to require at least the fifth of a second for sound to travel to it and return.

It is not possible to pronounce or to hear distinctly more than five syllables in a second. The velocity of sound being 1090 feet per second, it follows that sound travels 218 feet in one fifth of a second. If, then, an obstacle be placed at the distance of 109 feet, sound will go to it and return in one fifth of a second. At that distance the last syllable only of the echo will reach the ear after the sentence is pronounced. Such an echo is called *monosyllabic.* If the echo takes place from an obstacle at a distance of 218 feet, we hear two syllables; that is, the echo is *dissyllabic.* At distances of 327 feet, the echo is *trisyllabic;* and so on.

When sound is reflected from several surfaces situated in different directions and at different distances, *multiple echoes* are produced; that is, a single sound or syllable is repeated several times. The number of times that a single sound will be repeated depends upon the *number* of reflecting surfaces; the number of syllables or words that will be repeated after a speaker depends upon the *distance* of a single reflecting surface.

Sound is wasted by repeated reflections. Floors and partitions are deadened by means of mortar, sawdust, and the like, so that the heterogeneous mass by irregular reflection of the sonorous waves may diminish the intensity of the sound.

218. Acoustic Clouds. — It has generally been supposed that fogs, rain, snow, and hail interfere with the transmission of sound; but, according to experiments made by Tyndall, they seem to have no sensible power in obstructing sound, and therefore the connection supposed to exist be-

tween a clear atmosphere and the transmission of sound is dissolved. He also found that the air associated with fog is usually highly homogeneous and favorable to the transmission of sound.

He supposed the existence in the air, even in the clearest weather, of clouds of vapor impervious to sound, called *acoustic clouds*. These have no connection with ordinary clouds, fogs, or haze. The sound-waves are thrown back from these clouds, as light from ordinary clouds, and the intensity of the sound is weakened by repeated reflections.

The fact that sound is thus turned back may explain the variations in distance at which familiar sounds are often heard at different times, and especially why, at a given point, the sound produced by a cannon may be heard at some places and not at others equally distant from the spot. We may have days when the atmosphere is very transparent to the eye, but on account of the presence of acoustic clouds very opaque to the ear.

219. Resonance. — When sounds are reflected from a distance too small to produce a distinct echo, the effect is to strengthen the original sound. This effect is called *Resonance*.

It is the resonance from the walls of a room that makes it easier to speak in a closed apartment than in the open air. The resonance is more clearly perceived when the walls are elastic. In rooms where there are carpets, curtains, stuffed furniture, and the like, the sound-waves are broken up, and the resonance is diminished; but in houses where there is no furniture the resonance is strengthened. Hence it is that the sound of voices, footsteps, etc., is so strongly marked in deserted and unfurnished buildings.

220. Refraction of Sound. — Sound may be refracted, or bent out of its course, when passing from one medium to another of different density. This is shown in Fig. 158.

B is a collodion or rubber balloon filled with carbonic acid gas. The envelope is so thin that the sound-waves are transmitted to the gas inside.

Let a watch, *w*, be hung near this gas-lens, *B*. Now place the

ear a few feet from the lens, at *f*, using a glass funnel, *f'*, to assist the ear. By moving the funnel about, a position is found where the ticking is louder than elsewhere. The sound-waves are bent from their course, and brought to a focus at *f*.

The laws of reflected and refracted sound are the same as those of light, and will be treated under that subject.

221. Intensity of Sound.—This quality depends upon the *amplitude* of the vibrations, that is, the space through which the molecules move to and fro. It varies very nearly as the square of the amplitude of vibration of the molecules of air.

The intensity of sound diminishes as the square of the distance from the sonorous body increases; that is, *the in-*

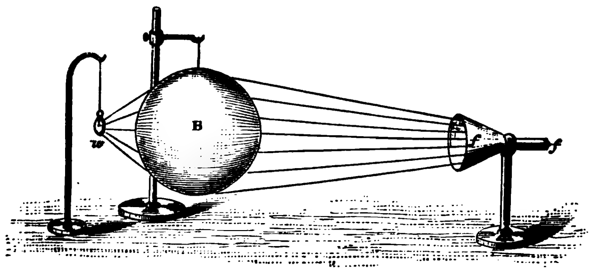


Fig. 158.

tensity of sound varies inversely as the square of the distance from the sonorous body.

The density of the air modifies sound. In rarefied air sounds are feeble, while in condensed air they are louder than in the ordinary atmosphere. The wind modifies sound. The velocity of sound is increased or diminished by the velocity of the wind, according as the direction of the wind conspires with or opposes the propagation. The effect of the wind is to move the whole mass of air, carrying along the sound-waves unaltered.

Sound is increased in intensity when the sonorous body is in contact with, or even in the neighborhood of another body capable of vibrating in unison with it. Hence the sound of a vibrating cord is reinforced or strengthened by stretching it over a thin box filled with air, as in the violin. In this case the air in the body of the

violin and the box vibrates in unison with the cord. The ancients placed in their theatres vessels of brass, to reinforce and strengthen the voices of the actors. The tuning-fork is often mounted on a wooden case, open at one or both extremities. The sound of the vibrating fork is thus intensified.

222. Intensity of Sound in Tubes. — When a sound is transmitted through a tube, the sound-waves cannot diverge laterally; and, consequently, the sound is conveyed to a great distance without much loss of intensity.

Biot was able to carry on a conversation in a low tone through a tube a thousand feet in length. He says the sound was transmitted so well that there was but one way to avoid being heard, and that was not to speak at all. This property of tubes is utilized in hotels and dwelling-houses, for transmitting messages from one story to another. The tubes employed for this purpose are called *speaking-tubes.*

223. The Speaking-Trumpet. — The Speaking-Trumpet, as its name implies, is a tin or brass tube, conical in shape, employed to transmit the voice to a great distance.

The effect of the speaking-trumpet has been explained by successive reflections of sound-waves from the sonorous material of which the instrument is composed, by virtue of which the voice is transmitted only in the direction of the tube.

But the fact is, that the sound transmitted is not merely stronger in direction of its axis, but in all directions. This would indicate that its effect should be attributed to a reinforcement of the voice by the vibration of the column of air contained in the trumpet in unison with it, according to the principle that sound is reinforced by an auxiliary vibrating body.

224. The Ear-Trumpet. — The Ear-Trumpet is employed by persons whose hearing is defective. It is simply the speaking-trumpet reversed, although the principle is the same. It consists of a conical tube, turned in any convenient direction, so that the smaller opening may enter the ear.

It serves to collect and concentrate the sound-waves, which are

thus enabled to produce a more powerful impression on the drum of the ear. The shape of the ear in man and in animals is such as to perform the function of the trumpet.

Summary. —

Production of Sound.
Illustrated by a Stretched Cord.
Sound-Waves in Air.
Propagation illustrated by Tuning-Fork and Bell.
Combinations of Sound-Waves.
Coincidence and Interference of Sound-Waves.
Illustrated by a Tuning-Fork.
Sound increased by Coincidence of Sound-Waves.
Sound destroyed by Interference of Sound-Waves.
Examples.
Beats.
Definition.
Illustrated by Tuning-Fork.
Examples.
Propagation of Sound.
In the Air and in a Vacuum.
In Liquids and Solids.
Velocity of Sound in Air.
Examples to determine its Velocity.
Effect of the Density and Elasticity on its Velocity.
The Law of its Velocity.
Velocity of Sound in Liquids.
Experiment to determine the Velocity.
Velocity of Sound in Solids.
Greater in Dense and Elastic Bodies.
Examples of its Velocity in different Solids.
Reason for the Velocity of Sound through Liquids and Solids being greater than through Air.
Reflection of Sound.
Echoes. — How formed.
Examples.
Multiple Echoes.
Sound wasted by Reflections.
Acoustic Clouds.
Explanations.

Reflection of Sound (continued).
Effect of these Clouds on Sound.
Resonance.
Refraction of Sound.
Illustrated with Balloon and Watch.
Intensity of Sound.
Law of Intensity.
Modified by the Wind.
Modified by Contact with a Sonorous Body.
Intensity of Sound in Tubes.
Speaking-Tube.
Speaking-Trumpet.
Ear-Trumpet.

SECTION II. — MUSICAL SOUNDS.

225. A Musical Sound results from a succession of vibrations at equal intervals and of sufficient rapidity.

226. Noise results from a single impulse, or from a succession of vibrations at irregular intervals. Thus, the crack of a whip, the discharge of a pistol, the rattling of thunder, the roar of the waves of the ocean, are destitute of musical value, and are simply noises.

The difference between a musical sound and a noise can be illustrated by SAVART's Wheel (Fig. 159). This consists of a heavy frame supporting two wheels, *A* and *B*, which are connected by a band, *D*.

By turning the crank, *M*, the toothed wheel, *B*, can be made to revolve with great rapidity. If a card be held against the teeth, when in rapid motion, a very shrill musical tone is produced, which becomes less shrill as the speed slackens, until the separate taps of the teeth against the card are heard.

We see that when the taps recur with sufficient frequency, that is, more than 16 per second, so as to form a continuous sound, the effect is musical. If the card strikes against the wheel less than 16 teeth per second, the separate taps only will be heard, but no musical tone will be recognized.

We have at *H* an apparatus for indicating the number of revolutions of the toothed wheel. The card, being struck by each tooth, makes as many vibrations as there are teeth. Multiply the number of revolutions by the number of teeth in the wheel, and we have the total number of vibrations. Divide the product by the number of seconds, and we get the number of vibrations per second.

227. **Pitch of Sounds.** — The Pitch of a musical sound depends upon the frequency of the vibrations. This was shown in Fig. 159.

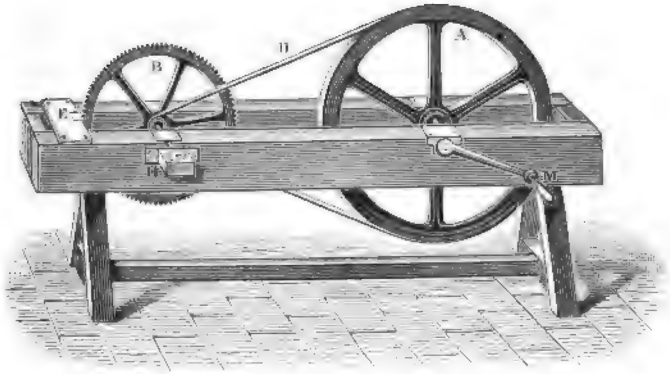


Fig. 159.

The faster the wheel turns the more rapid are the vibrations of the card, and the shriller is the sound, or, in other words, the higher the pitch. The slower the wheel turns, the reverse is the case.

228. **Music.** —Those sounds which result from very rapid vibrations are called *acute*, whilst those which arise from very slow vibrations are called *grave*.

The intensity, or loudness, of musical sounds, as in the case of other sounds, depends on the amplitude of the vibrations.

229. **The Siren.** — The Siren is an instrument used for producing musical tones, and at the same time determining the number of vibrations.

It consists (Fig. 160) of a cylindrical box of brass, *C; t* is

a tube opening into it from below, for the purpose of admitting air. The top of the cylinder is covered with a brass plate, *a b*; this is perforated with four series of holes arranged in four concentric circles, containing 8, 10, 12, and 16 apertures respectively; *d e* is a brass disk, also perforated with four series of holes, corresponding, in their general arrangement and distance from one another, with those in the plate, *a b*, below.

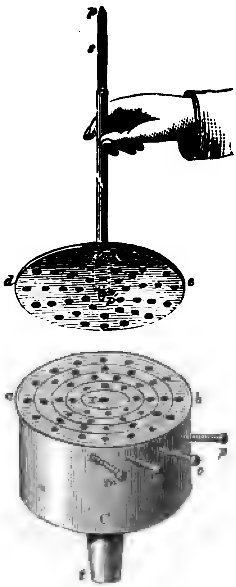


Fig. 160.

Through the centre of this disk passes a steel axis whose ends, *p* and *p′*, are smoothly bevelled, *p′* to fit into the socket, *x*, and *p* to receive a brass cap when the instrument is ready for use.

The perforations do not pass perpendicularly through the plates, but slope in opposite directions, so that when air is forced through the holes in the lower plate, it will impinge on one side of the holes in the upper plate, and thus blow it round in a definite direction. As it revolves, the holes in *a b* are alternately opened and closed. The air coming into the cylinder through the tube, *t*, thus escapes through the aperture in its upper plate in a succession of puffs. The puffs come through slowly at first and can be counted, but as the disk rotates faster and faster they unite their vibrations into a musical note, the pitch of which is higher in proportion to the increase of velocity.

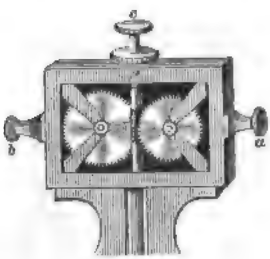


Fig. 161.

The revolutions of the disk are registered by means of the apparatus shown in Fig. 161. On the upper part of the axis of the disk is an endless screw connecting with a pair of toothed

wheels. By pushing *a*, the recording apparatus is set in motion, and by pushing *b* the motion is stopped.

In Fig. 162 are seen the graduated dial-plates on the front of the Siren. The indexes of each dial are connected with the clock-work just described. They move over the dials with the revolutions of the wheels, and register the revolutions. The stops, *m*, *n*, *o*, *p*, are used to open or close the different series of orifices.

230. Method of determining the Rapidity of the Vibrations of a Sonorous Body. — Let air be forced into the Siren by means of bellows. Note carefully when the tone of the Siren blends with that of the sounding body, the number of whose vibrations we wish to ascertain. Suppose the outer series to be open, sixteen in number, allow the disk to vibrate one minute, then read from the dials the number of revolutions it has made.

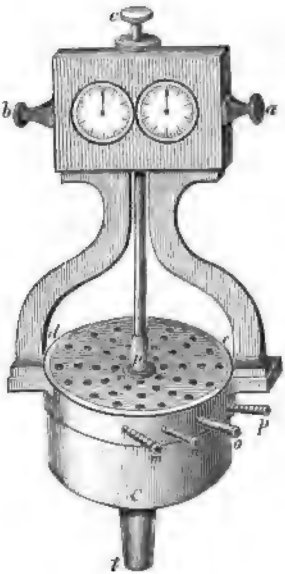


Fig. 162.

We will suppose the number to be 1440, but for every revolution of the disk there were 16 puffs of air or sound-waves; therefore the whole number is found by multiplying 1440 by 16, which gives a result of 23,040. This number also represents the vibrations of the sounding body. Divide this result by 60, and we get 384, the number for one second.

Musical tones are in unison when the number of vibrations in a second is the same.

If the inner series of holes should be opened, the tone produced would be an octave lower than that made by the outer row, the vibrations being one half as many. Hence the octave of any tone is found by multiplying the vibrations of the tone by 2; if we double the vibrations of the octave, we get *its* octave, and so on.

231. Length of the Sound-Wave. — The distance through which a sound-wave travels in one vibration of the sonorous body is the *wave-length*, and by knowing the velocity of sound for any temperature the length of the sound-wave can be easily found.

Suppose the temperature is such as to give a velocity of 1120 feet per second for the foremost wave. There are 384 sonorous waves. Dividing 1120 by 384, we find the length of each wave to be about 3 feet. If the number of waves be 512, the wave-length would be 2 feet 2 inches. Therefore the higher tones are produced by the shorter waves; the grave, or lower ones, by the longer.

The ordinary pitch of a woman's voice is considered to be an octave above a man's in the lower sounds of conversation; in the higher, about two octaves. The sound-waves generated by a man's vocal organs in ordinary conversation are from 8 to 12 feet, those of a woman 2 to 4. The human ear is limited in its range of hearing musical sounds. Helmholtz has fixed the lower limit at 16 vibrations, and the higher at 38,000, per second.

Summary. —

Musical Sounds.
- Difference between a Musical Sound and a Noise.
  - Illustrated by Savart's Wheel.
- Method of finding the Number of Vibrations per Second.
- Pitch of Musical Sounds.
  - Illustrated by Savart's Wheel.
- Intensity of Musical Sounds.

The Siren.
- Construction.
- Mode of Operation.
- Method of recording the Vibrations of a Sounding Body.
- Method of finding the Number of Vibrations per Second.
- Unison of Musical Tones.
- Rule for finding the Octave of any Tone.

Length of Sound-Waves.

Limit of the Human Ear in hearing Musical Sounds.

232. Transverse Vibrations of Cords. — We have already seen (Art. 207) that when a stretched cord is drawn from its position of equilibrium and abandoned, it returns to

its position of rest by a succession of continually decreasing vibrations.

Cords used in musical instruments are generally made of catgut or of twisted wires. They are made to vibrate by drawing a bow across them, as in the violin; by drawing them aside, as in the harp; or by percussion with little hammers, as in the piano. In all of these cases the vibrations are *transversal*, that is, the movements take place perpendicularly to the direction of the cord.

The number of vibrations of a stretched cord in any given time, as in one second, for example, depends upon its length, its thickness, its tension, and its density.

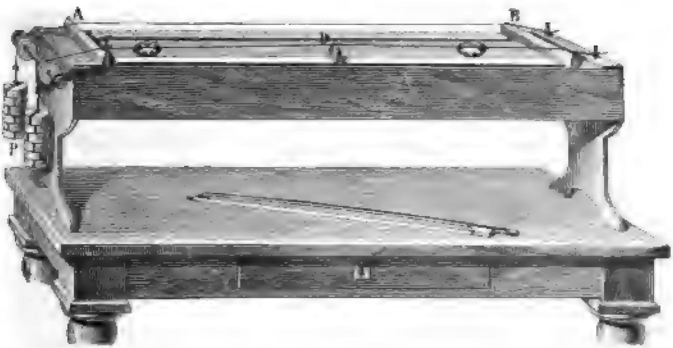


Fig. 163.

233. Investigation of the Laws of Vibrations.—For studying the vibrations of cords, an instrument called the *Sonometer* (Fig. 163) is used. In its present form it consists of a wooden box about four feet in length, upon which are mounted two fixed bridges, *A* and *B*, and a movable one, *D*. On these bridges, two cords, *C D* and *A B*, fastened firmly at one end and passing over pulleys at the other end, are stretched by means of weights, *P*.

The following are the laws that govern the number of vibrations of a cord in a fixed time: —

1. *The tension being constant, the number of vibrations varies inversely as its length.*

If a given cord makes 18 vibrations per second, it will make 36 if its length be reduced to one half, 54 if its length be reduced to one third, and so on. This property is utilized in the violin. By applying the finger, we virtually reduce the length of the vibrating portion at pleasure.

2. *The tension and length being the same, the number of vibrations varies inversely as its diameter.*

Small cords vibrate more rapidly than large ones, and consequently render more acute sounds. A cord of any given size makes twice as many vibrations as one of double the size. Other things being equal, the notes rendered differ by an octave.

3. *The length and size being the same, the number of vibrations varies as the square root of the tension.*

If a cord renders a given note, it will, if its tension be quadrupled, render a note an octave higher, and so on. This property is utilized in stringed instruments by means of an apparatus for increasing or diminishing the tension at pleasure.

4. *Other things being equal, the number of vibrations varies inversely as the square root of the density.*

Dense cords render graver notes than those of less density. Small, light, and short cords, strongly stretched, yield acute notes. Large, dense, and long cords, not strongly stretched, yield grave notes.

234. Verification of the Laws.—These laws can be verified as follows:—

Let the cords be exactly alike and stretched by equal weights. If the bridge, *D*, be moved so as to render *C D* equal to one half of *A B*, the notes of the two cords will differ by an octave; that is, *C D* will vibrate twice as fast as *A B*. If *C D* be made equal to one third of *A B*, by moving the bridge, *D*, the former will vibrate three times as fast as the latter, and so on. This verifies the *first* law.

To verify the *second* law, we remove the bridge, *D*, and use two cords, one of which is twice as large as the other. It will be found that the notes yielded will differ by an octave. If one cord is three

times as large as the other, the latter will be found to vibrate three times as fast as the former.

To verify the *third* law, let the two cords be alike, and stretch one by a weight four times as great as that employed to stretch the other. The notes will differ by an octave. If the stretching force in

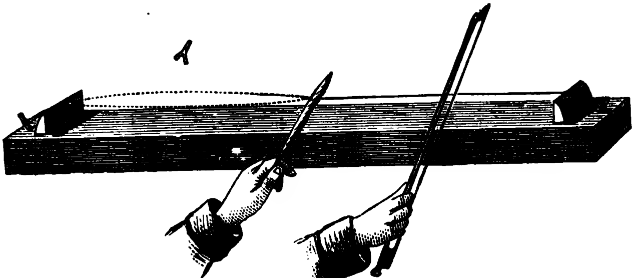


Fig. 164.

one is nine times that in the other case, the former will vibrate three times as fast as the latter, and so on.

To verify the *fourth* law, we make use of cords equal in length, size, and equally stretched, but of different densities. It will be found that the law is verified in every case.

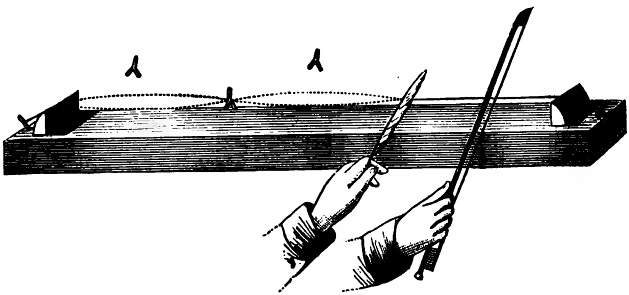


Fig. 165.

235. The Formation of Nodes. — In the Sonometer the cord is shortened by means of a movable bridge which holds it firmly. If, instead, we place a feather on the centre of the cord (Fig. 164), and draw a bow across one half of it, we shall get the octave of the tone given by the whole string.

We can prove that each part vibrates by itself if we place a little paper rider on the centre of one half the string, and then draw the bow across the other half, keeping the feather meanwhile on the middle of the whole string. The rider will be thrown off by the vibrations of the part on which it is placed.

Hold the feather one third the distance from the end of the wire (Fig. 165), and place a blue rider on the centre of the larger division and a red one on the middle of each half of this division. Draw the bow over the shorter segment. The red riders will be thrown off, but the blue one will remain; showing that the larger division vibrates in two equal segments, which are separated from each other by a stationary point called a *node*.

If the feather be removed, the entire string will continue to vibrate in these equal divisions with the nodes between them. In the same way a wire may be divided into four, five, six, or any number of vibrating parts, separated by nodes. In fact, it is impossible to sound the whole cord without at the same time producing, in a greater or less degree, the vibrations of its aliquot parts.

236. Melde's Vibrations of a String. — A simple device by Melde exhibits the vibrations of a string with great beauty and delicacy. One end of a silk string is attached to a screw fastened to one prong of a tuning-fork; the other end is wound about a peg some distance off.

Tighten the string by turning the peg, until it vibrates as a whole, when the bow is drawn across the fork. The string at once expands into the form of a spindle whose gossamer threads present a beautiful appearance. Let the string be relaxed a little, and we have two vibrating segments; relax still more, and we have three; and if we continue the process, twenty and more may be obtained. The stationary nodes contrast finely with the oscillating segments.

237. Longitudinal Vibrations. — Strings or wires may also be made to vibrate longitudinally by rubbing them in the direction of their length with a bow or piece of chamois-leather covered with rosin. The sounds thus obtained are of much higher pitch than those produced by transversal vibration. *The shorter the wire the more rapid the longitudinal*

vibrations and the higher the pitch. This is independent of the form or diameter of the sections. Rub one of the wires of the sonometer with resined leather in the direction of its length, and we have a musical sound. Move the bridge so as to divide the wire into two equal parts, rub one of the halves, and the octave of the whole wire is given. This law holds true in regard to rods as well as wires. If we change the tension of the wire, the longitudinal vibrations are unaltered.

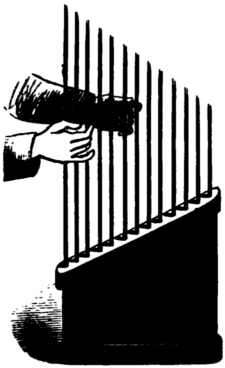


Fig. 166.

A musical instrument to show the longitudinal vibrations has been constructed (Fig. 166) something like a harp in appearance, composed of wooden rods of different lengths fixed at one end, so that notes of different pitch are emitted. The rods are set in vibration by rubbing them with the resined fingers.

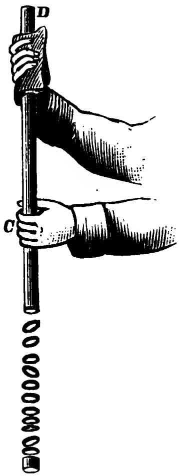


Fig. 167.

If we grasp a long glass tube by its centre with one hand, and rub the upper half briskly with a wet cloth in the other hand, the longitudinal vibrations may be sufficient to shiver the end farthest from the hand into ring-shaped fragments, as seen in Fig. 167.

238. Sympathetic Vibrations. — If a tuning-fork is made to vibrate, another fork of the same pitch anywhere in the vicinity will be thrown into vibrations also by the impact of the sound-waves in the air; if the forks are mounted on resonant boxes, the sound will be intensified by resonance and the effect be better.

The sound-board of the violin vibrating with the strings, and, in fact, all cases of resonance are really instances of sympathetic vibration. If a tone is prolonged by the voice

near a piano, a wire of the same pitch as the tone will respond to it. If the pitch be changed, another wire will respond.

Many examples might be brought forward to illustrate this topic. "If two clocks, for example, with pendulums of the same period of vibration, be placed against the same wall, and if one of the clocks be set going and the other not, the ticks of the moving clock, transmitted through the wall, will act upon its neighbor. The quiescent pendulum, moved by a single tick, swings through a very small arc, but it returns to the limit of its swing just in time to receive another impulse. By continuance of this process the impulses so add themselves together as finally to set the clock going. It is by this timing of impulses that a properly pitched voice can cause a glass to ring, and that the sound of an organ can break a particular window-pane."

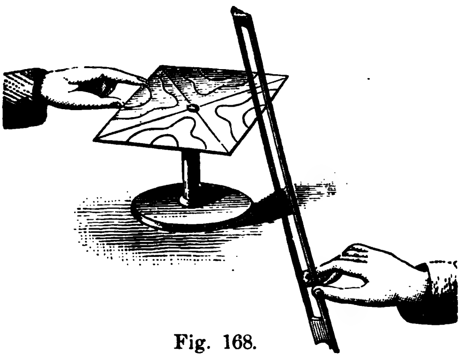


Fig. 168.

239. Vibration of Plates.—Fig. 168 represents a plate of metal supported at its centre. Sprinkle some fine, dry sand over it. Hold the thumb and finger on one edge of the plate, and draw the bow lightly across the opposite edge.

The sand at once leaves the vibrating parts and accumulates on the nodal lines. These lines vary in number and position according to the form of the plates, their elasticity, the mode of excitation, and the number of vibrations. By touching the vibrating plate at different points, the position of the nodal lines may be determined. In Fig. 169 may be seen some of the nodal forms obtained by CHLADNI.

Nodes may be formed in a similar way in bells, and all other sounding bodies.

240. Overtones, or Harmonics. — It has been shown, by the experiments just given, that a stretched string vibrates as a whole, and at the same time in equal parts. The same may be said of any sounding body. Tones of simple character cannot, therefore, be given out by vibrating bodies.

When the body vibrates as a whole, the tone produced is called the *fundamental.* The higher tones are made by the vibration of the equal parts, and are called *harmonics*, or *overtones.* By pitch we also mean the fundamental sound.

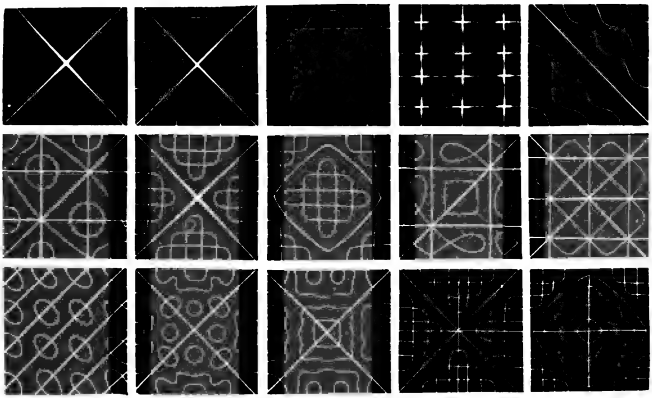


Fig. 169.

241. Quality. — Timbre. — The mingling of the overtones with the fundamental determines the *quality* or *character* of the sound, called by the French, *timbre.*

Thus we can understand why it is when different instruments, like the piano, the violin, or the flute, are giving the same fundamental sound, that they have such different characteristics as to enable us instantly to identify them. The human voice is rich in overtones. The superiority of one singer over another is undoubtedly due, in a great measure, to a much finer mingling of the overtones with the fundamental tone.

242. Musical Scale. — Gamut. — The ear not only distinguishes between given sounds, — which is most grave, and which is most acute, — but it also appreciates the relations between the number of vibrations corresponding to each. We cannot recognize whether for one sound the number of vibrations is precisely two, three, or four times as great as for another, but when the number of vibrations corresponding to two successive or simultaneous sounds have to each other a simple ratio, these sounds excite an agreeable impression, which varies with the relation between the two sounds.

From this principle there results a series of sounds characterized by relations which have their origin in the nature of our mental organization, and which constitute what is called a *musical scale*.

The whole series of musical tones is divided into octaves, or groups of eight tones each. Each group constitutes what is called the *gamut*, or *diatonic scale*.

The notes are named *do, re, mi, fa, sol, la, si, do;* but they are designated by the letters *C, D, E, F, G, A, B, C.* In the table below is given the relative number of vibrations for each note, 1 denoting the number corresponding to *C*: —

1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
C	*D*	*E*	*F*	*G*	*A*	*B*	*C*

The relative lengths of strings required to produce the eight notes of the scale are expressed by the reciprocal of these quantities, as follows: —

1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
C	*D*	*E*	*F*	*G*	*A*	*B*	*C*

If we know the number of vibrations of *C*, we can find the others by multiplying those of *C* by the fractions placed over the other notes in the first table. Let 256 represent the vibrations of *C*, then the following numbers will denote the vibrations for each note: —

256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512
C	*D*	*E*	*F*	*G*	*A*	*B*	*C*

There are really but seven notes in what is called the diatonic scale, the eighth note, *C*, being truly the first of seven other notes above, having relations to one another similar to those of the notes below, and constituting another octave.

The results obtained in these tables can be verified by the Siren and Sonometer.

243. Intervals. — The interval between any two notes is called a *musical interval*.

The numerical value of any interval is found by dividing the number of vibrations in a given tone by the number of vibrations in that preceding it.

The intervals between consecutive notes, called seconds, is given in the following table: —

C to *D*,	*D* to *E*,	*E* to *F*,	*F* to *G*,	*G* to *A*,	*A* to *B*,	*B* to *C*.
$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

If the interval comprise *two*, *three*, *four*, etc., *seven* notes, it is called *a third*, *a fourth*, *a fifth*, etc., *an eighth* or *an octave;* thus, the interval between *C* and *E* is *a third*, and is equal to $\frac{5}{4}$; the interval from *C* to *F* is *a fourth*, and is equal to $\frac{4}{3}$; the interval from any note to the next note of the same name is *an octave*, and is always equal to 2.

In the following table is a summary of the results already given, for one octave of the diatonic scale, arranged on the musical staff: —

Name of interval .	1st	2d	3d	4th	5th	6th	7th	8th
Syllables . . .	*Do*	*Re*	*Mi*	*Fa*	*Sol*	*La*	*Si*	*Do*
Names by letters .	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*
Relative number of vibrations	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Absolute number of vibrations	256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512
Scale of intervals		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

244. Melody. — A number of tones of like quality, varying more or less in pitch, following one another with regularity, is called a *melody*.

The *air* in a piece of music is an example of melody.

245. Chords. — Harmony. — Discord. — When two or more sounds are produced at the same time, having agreeable relations to one another, we have a *chord*.

A succession of chords in melodious order constitutes *harmony*.

The *air*, in music, with accompaniment, is an example of harmony.

When these agreeable relations do not exist, we have *discord*.

The simplest and most agreeable harmony occurs when the vibrations are equal in number; then comes *the octave*, in which the number of vibrations corresponding to one sound is double that corresponding to the other; then *the fifth*, in which the numbers are as 3 to 2; then *the fourth*, in which the numbers are as 4 to 3; and finally *the third*, in which the ratio is that of 5 to 4.

The more frequent the coincidences between the vibrations, the greater the harmony.

Summary. —

Transverse Vibrations of Cords.

Investigation of the Laws of Vibrations.

Description of the Sonometer.
Laws of Vibrations.
Verification of the Laws.

Formation of Nodes.

Illustrated with the Sonometer.
Position of Nodes on a String.
Vibration of the String as a Whole or in Segments.

Longitudinal Vibrations of Wires and Rods.

Experiments.

Vibration of Plates.

Experiment with Plate and Sand.
Chladni's Nodal Forms.

Overtones, or Harmonics.

Quality, or Timbre, of Sounds.

Musical Scale.

Names of Notes.

Letters used in designating Notes.

Relative number of Vibrations of each Note, in Tabulated Form.

Relative length of Strings to give each Note, in Tabulated Form.

Absolute number of Vibrations for each Note, in Tabulated Form.

A Musical Interval.

Tabulated results on the Musical Staff.

Melody. — Harmony. — Discord.

SECTION III. — OPTICAL STUDY OF SOUNDS. — MUSICAL INSTRUMENTS. — THE HUMAN VOICE AND EAR. — THE PHONOGRAPH.

246. Optical Study of Sounds. — It has been shown in a previous article how the vibrations executed by a sonorous body can be counted. The Siren and SAVART'S Wheel are instruments used for this purpose.

During the last few years physicists have studied carefully the vibratory motions of sounding bodies by means of the eye, and have thus been independent of the aid of the ear in determining the relationship of sounds. A deaf person, by this optical method, can become skilful in judging of the character and pitch of sound-waves.

247. Lissajous' Representation of Vibrations. — One of the best methods of making vibrations apparent has been devised by M. LISSAJOUS, a French physicist. He attaches a small metallic mirror to one prong of a tuning-fork, and to the other a counterpoise to secure regularity of vibrations. A ray of light from a hole in a darkened chimney, a few yards distant, is made to strike this mirror, and from this it is reflected to another mirror, which sends it to an achromatic,

convergent lens; this lens is so placed as to project the images on a screen.

When the fork is at rest, we have on the screen a luminous point, the image of the hole in the chimney; when it vibrates the mirror vibrates with it, and the point moves up and down with such rapidity as to leave a line of light on the screen. If we rotate the fork while it is vibrating, we get instead of the straight line a bright sinuous one. The position of the parts is shown in Fig. 170, except that the fixed mirror takes the place of the vertical tuning-fork.

248. Vibratory Motions at Right Angles. — If we use two forks, one horizontal and the other vertical, both provided with mirrors and arranged as in Fig. 170, we shall have thrown on the screen a variety of images.

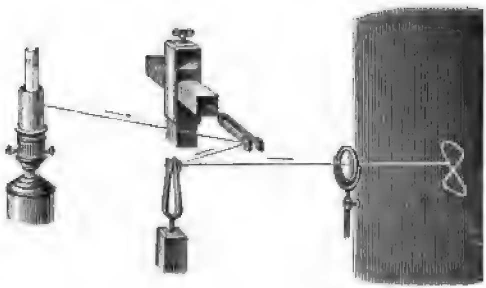


Fig. 170.

If the vertical fork vibrates, we perceive a luminous line in a vertical direction; if the horizontal one vibrates, while the vertical fork is at rest, the luminous line is horizontal.

If both forks vibrate at the same time, the two movements at right angles will combine and produce a luminous curve, the form of which will depend upon the number of vibrations of the two forks in a given time. The arrows show the direction of the ray of light in its passage to the screen. Some varieties of curve are represented in Fig. 171.

By the aid of these principles, tuning-forks can be compared with a standard fork with greater precision than would be the case with the most susceptible ear.

LISSAJOUS' figures can also be produced by means of the vibrations of a pendulum in a slower and easier way than by means of the tuning-fork.

249. Kaleidophone. — The optical study of vibrating rods can be made by means of an apparatus called the *kaleidophone*. This can be constructed by a very simple process. Insert, with the aid of an awl, a knitting-needle with a glass bead on the end, firmly in an inch board several inches

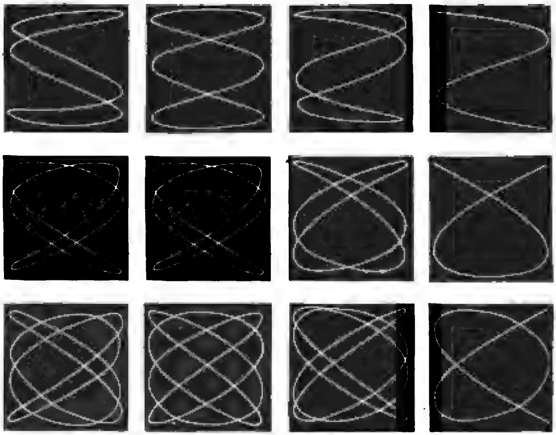


Fig. 171.

square. Place the board on a table, and hold it tightly with the hand while the needle vibrates.

Allow the light of a lamp to fall upon the bead when still, we have a small spot on the screen intensely illuminated; now cause the needle to vibrate, and the spot will be drawn out into a brilliant line which will change into a circle; and thus the character of the vibrations is shown.

250. Koenig's Manometric Flames. — Other ingenious instruments have been constructed for illustrating the optical method. The apparatus of KOENIG transmits the movements

of the sound-waves to gas-flames, and these, by their pulsations, show the nature of the sound.

We have, in Fig. 172, a metal capsule, *A*, in section. This is divided into two compartments by a membrane of gold-beater's skin or thin rubber. Immediately below the section, *A*, is seen the capsule supported on a stand; on the right is the gas-jet, below it the tube for conveying the gas to the compartment at the right of the membrane; on the left is the tube for the sound-waves to reach the membrane. To this may be attached a rubber tube, which can terminate in a mouth-piece or be connected with an organ-pipe.

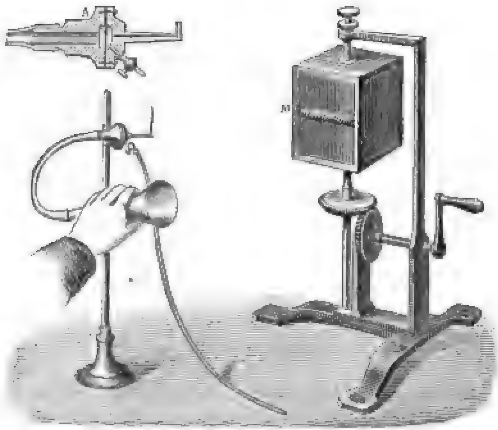


Fig. 172.

When the sound-waves enter the mouth-piece and tube, the thin membrane is set vibrating. The gas, while passing through the compartment at the left, is caused to vibrate in a corresponding way, and thus the flame itself is shaken up and down.

The changes in the length of the flame are scarcely perceptible when it is observed directly. But to make them distinctly visible they may be received on a mirror, *M*, with four faces. This is made to revolve by means of two cog-wheels and a handle.

While the flame burns steadily there appears in the mirror, when turned, a continuous band of light. But if the fundamental note is sounded in the tube on the left of the capsule, the image of the flame

takes the form represented in Fig. 173. If the octave be sounded, the image of the flame takes the form seen in Fig. 174.

Many varieties of forms can be produced when several sounds of different intensities enter the tube simultaneously.

These flames just described are called *manometric flames.* The succession of separate images of the flames, which we see on turning the mirror, is due to the fact that the image of an object remains on the retina for a little time after the object itself has been removed.

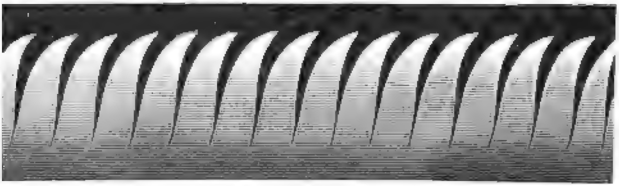


Fig. 173.

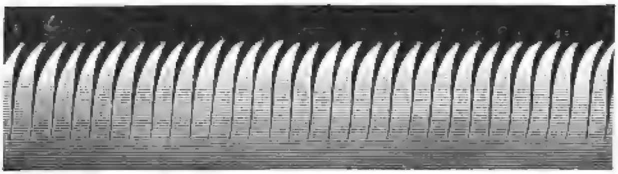


Fig. 174.

251. Stringed Instruments. — All stringed instruments of music are constructed in accordance with the preceding laws. They are divided into instruments with *fixed sounds*, and instruments with *variable sounds.*

To the former class belong the piano, the harp, etc. They have a cord for each note, or else an arrangement is made so that by placing the finger at certain points, as in the guitar, the same cord may be made to render several notes in succession.

To the latter class belong the violin, the violoncello, etc. They are provided with cords of catgut, or sometimes of metal, put in vibration by a bow. Various arrangements

are made for regulating the notes, such as increasing the tension, placing the finger upon the cords, and the like. These instruments are difficult to play upon, and require great nicety of ear, but in the hands of skilful players they possess great power. They are the soul of the orchestra, and it is for them that the finest pieces of music have been composed.

252. Sound from Pipes.—When the air in a *pipe*, or hollow tube, is put into vibration, it yields a sound. In this case it is the air which is the sonorous body, the nature of the sound depending upon the form of the pipe and the manner in which the vibrations of its contained air are produced.

To produce a sound from a pipe, the contained air must be thrown into a succession of rapid condensations and rarefactions, which is effected by introducing a current of air through a suitable *mouth-piece.* Two principal forms are given to the mouth-piece, in one of which the parts remain fixed, and in the other there is a movable tongue, called a *reed.*

253. Pipes with fixed Mouth-pieces. — Pipes with fixed mouth-pieces are of wood or metal, rectangular or cylindrical, and always of considerable length compared with their cross section. To this class belong the flute, the organ pipe, and the like. Some of the forms given to pipes of this class are shown in Figs. 175–179.

Fig. 175 represents a rectangular pipe of wood, and Fig. 176 shows the form of its longitudinal section. *P* represents the tube through which air is forced into it. The air passes through a narrow opening, *i*, called the *vent.* Opposite the vent is an opening in the side of the pipe, called the *mouth.* The upper border, *a*, of the mouth is bevelled, and is called the *upper lip;* the lower border is not bevelled, and is called the *lower lip.*

The current of air forced through the vent strikes against the upper lip, is compressed, and by its elasticity, reacts upon the entering current, and for an instant arrests it. This stoppage is only for

an instant, for the compressed air finds an outlet through the mouth, again permitting the flow. No sooner has the flow commenced than it is a second time arrested as before, again to be resumed, and so on.

This continued arrest and release of the current gives rise to a succession of vibrations, which are propagated through the tube, causing alternate and rapid condensations and rarefactions, which

Fig. 175.

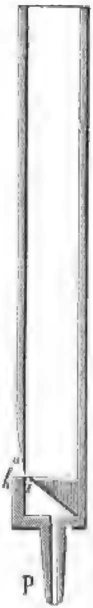


Fig. 176.

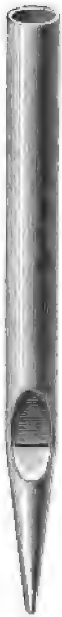


Fig. 177.

Fig. 178.

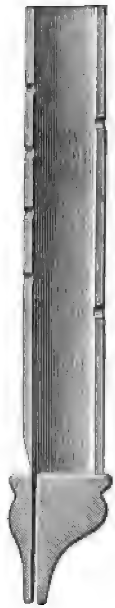


Fig. 179.

result in a continuous sound. The vibrations are the more rapid as the current introduced is stronger, and as the upper lip approaches nearer the vent.

Fig. 177 represents a second form of organ pipe, which is shown in section in Fig. 178. This is but a modification of the pipe already explained. The letters indicate the same parts as in the preceding figures.

An open organ-pipe yields a note an octave higher than that of a closed pipe of the same length. When a stopped organ-pipe sounds its fundamental note, the column of air is undivided by any node; but the closed end will always be a node, because the air particles at that part are necessarily at rest. When an open pipe sounds its fundamental note, the column is divided by a node at its centre. The open pipe really consists of two stopped pipes with a common base.

The existence of nodes and vibrating segments within an organ pipe may be shown by lowering into the pipe a thin membrane stretched over a frame, with some fine, dry sand sprinkled on its surface. The front of the pipe is of glass, so that we can see any body in it. When the sand is in a segment it will be agitated, but when it is in a node it will remain at rest.

If a node is connected with KOENIG'S capsule, the flame is more violently agitated than when a segment is joined. This is owing to the continual change in the density of the air taking place at the node, while at a segment the density is not sensibly changed, although the air is in a state of vibration.

Fig. 179 represents the form of the mouth-piece of the flageolet, and it will be seen that it bears a close resemblance to the pipes already explained. In the flute, an opening is made in the side of the pipe, which changes the length of the segments of the columns of air that are vibrating, and thus determines the pitch of the tone. The arrest and flow of the current are effected by the arrangement of the lips of the player.

254. Reed Pipes. — In REED PIPES the mouth-piece is provided with a vibrating tongue, called a *reed*, by means of which the air is put in vibration. To this class belong the clarinet, the hautboy, and the like. The reed may be so arranged as to beat against the sides of the opening, or it may play freely through the opening in the tube.

Figs. 180 and 181 show the arrangement of a reed of the first kind. A piece of metal, *a*, shaped like a spoon, is fitted with an elastic tongue, *l*, which can completely close the opening. A piece of metal, *r*, which may be elevated or depressed by a rod, *b*, serves to lengthen or shorten the vibrating part of the reed. This arrangement enables us to diminish or increase the rapidity of vibration at pleasure.

The mouth-piece, as described, connects with the tube, *T*, and is set in a rectangular box, *K N*, which is in communication with a bellows, from which the wind is supplied. For the purpose of class demonstration, the upper part of the tube, *K N*, has glass windows on three sides to show the motion of the reed.

When a current of air is forced into the tube, *K N*, the reed is set in rapid vibration, causing a succession of rarefactions and conden-

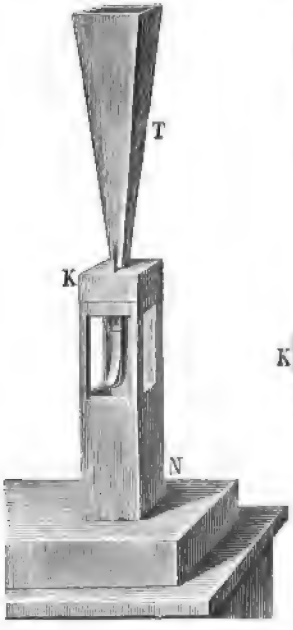


Fig. 180.

Fig. 181.

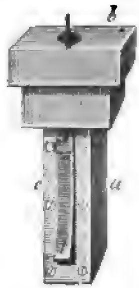


Fig. 182.

sations in the air of the pipe, *T*, and causing it to emit a sound. The air entering the tube, *K N*, first closes the opening by pressing the reed against it; the reed then recoils by virtue of its elasticity, permitting a portion of condensed air to enter the pipe, when the reed is again pressed against the opening, and so on as long as the current of air is kept up. It is evident that the rapidity of vibration will be increased by increasing the tension of the air from the bellows, and also by shortening the vibrating part of the reed.

Fig. 182 shows the arrangement of the free reed. The vibrating plate, *l*, is placed so as to pass backwards through an opening in the side of the tube, *c a*, alternately closing and opening a communication between the tube and the air from the bellows. The regulator, *r*, is entirely similar to that shown in Figs. 180 and 181, as are the remaining parts of the arrangement. The explanation of the action of this species of reed is entirely similar to that already described.

255. Wind Instruments.—WIND INSTRUMENTS of music consist of pipes, either straight or curved, which are made to sound by a current of air properly directed.

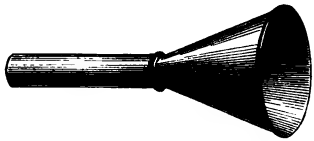


Fig. 183.

In some, the current of air is directed by the mouth upon an opening made in the side, as in the flute. In others, the current of air is made to enter through a mouth-piece, as in the flageolet. In others, a reed is used, as in the clarinet. In the organ there is a collection of tubes, similar to those shown in Figs. 175 and 177. In some instruments, as the trumpet and the horn, a conical mouth-piece is used, of the form shown in Fig. 183, within which the lips of the musician vibrate in place of the reed. The rapidity of vibration can be regulated at will.

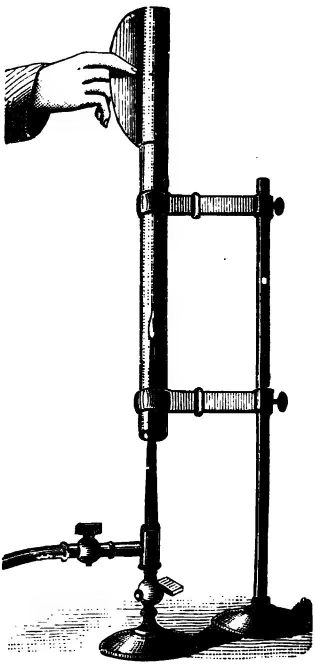


Fig. 184.

256. Sounding Flames.—When a gas-flame is enclosed in a tube, open at both ends, the passage of the air over it is generally sufficient to produce the

necessary rhythmic action, and to cause it to give out a musical tone. Fig. 184 represents such a tube firmly held in position by clamps, which are fastened by screws to a stand.

By means of the paper slider, *s*, the tube may be lengthened or shortened. While the flame is sounding, raise the slider, and the pitch falls; lower it, and the pitch rises.

By sounding the same note with the voice or any musical instrument, the singing of the flame may be interrupted, or caused to cease entirely; or, when silent, to begin again.

257. Sensitive Flames. —Flames are affected by sound-waves from musical tones even when not enclosed in tubes. The action of musical sounds upon such flames is shown by the vibrations of the gas-lights in unison with certain pulsations of the music at some instrumental concert. This phenomenon does not take place unless the pressure of gas is sufficiently great to keep the flames on the verge of flaring.

A long flame may be shortened and a short one lengthened by sonorous vibrations. Suppose we have a long smoky flame and a short, forked, and bright one, both on the point of flaring, and both issuing from a very small orifice, like a pin-hole in a tube. On sounding a whistle, their sensitiveness to the sound vibrations is at once apparent. The long flame becomes short, forked, and brilliant; and the forked, long and smoky. A flame may be shortened half its length by striking two pieces of wood or iron together.

258. The Human Voice. — The most perfect reed instrument is the human voice. Across the top of the trachea, or windpipe, are stretched two elastic bands, called *vocal chords;* through the space between the chords the air passes in and out of the lungs.

During speaking and singing the space between the chords is less than in ordinary breathing. The voice is produced by the air, which, driven from the lungs and striking against the chords, causes them to vibrate. The greater the tension of the chords the higher the pitch.

The mouth, by its resonance, reinforces the sound given out by the vibrating chords. By changing its shape it can be made to

resound to the fundamental tone, or any of the overtones of the vocal chords.

259. The Human Ear. — A section of the ear is seen in Fig. 185. It consists of the *external ear*, so formed as to enable it to catch the sound-waves. *B* represents the *auditory canal*, about an inch in length. A circular membrane, called the *membrane of the tympanum*, closes the lower end of it.

The *drum* of the ear, or the *tympanum*, is the cavity behind this membrane. Beyond the drum is the *labyrinth*. It consists of a

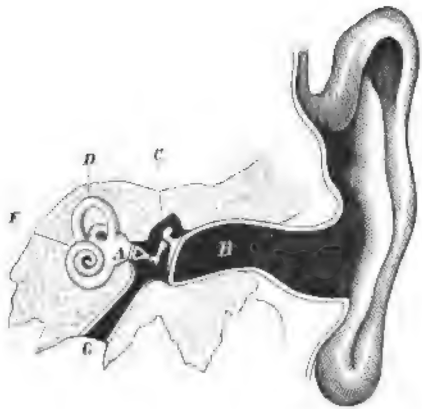


Fig. 185.

small rounded chamber, *A*, called the *vestibule;* from it open three *semicircular canals*, *D*, and a spiral canal, *E*, called the *cochlea*, from its resemblance to a snail-shell.

Through these canals the *auditory nerve* is distributed. From the membrane of the tympanum to the membrane of the vestibule a chain of three bones is stretched, the hammer attached to the membrane of the tympanum, the anvil, and the stirrup connected with the membrane of the vestibule. The vibrations of the atmosphere strike against the membrane of the tympanum, and are conducted through the chain of bones to the second membrane, and thence, by the auditory nerve, to the brain. The *Eustachian tube*, *G*, admits air to the drum, and thus keeps the density within the same as the external air.

260. The Phonograph. — The Phonograph is an instrument, devised by EDISON, to register sound-vibrations and to reproduce them at any time when desired.

It consists (Fig. 186) of a simple, small-sized iron cylinder, *C*, mounted upon a shaft, at one end of which is a crank, *M*, for turning it, the whole being supported by two iron uprights. In front of this cylinder is a movable arm that supports a mouth-piece, *E*, of gutta-percha, on the under side of which is a disk of thin, elastic metal. Against the centre of the lower side of this disk, a fine steel point, rounded at the end, is held by a spring attached to the rim of the mouth-piece. An india-rubber cushion between the point and disk controls the vibrations of the spring.

The cylinder is covered with a fine spiral groove running continuously from end to end, the threads being about $\frac{1}{10}$ of an inch apart. It works on a screw, *A A′*, the thread of which is the same

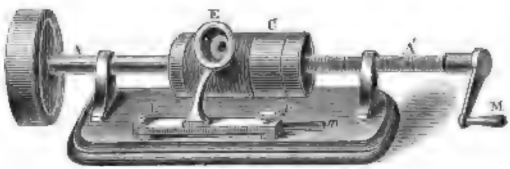


Fig. 186.

as that on the cylinder. It is turned by the handle, *M*, the motion being regulated by a heavy fly-wheel. The position of the mouth-piece and its pressure against the tinfoil are adjusted by the arrangement, *L v m*.

In using the phonograph, a sheet of tinfoil is wrapped closely around the cylinder. The mouth-piece is then adjusted against the left-hand end of the cylinder so closely, that when one speaks or sings into the mouth-piece, and at the same time turns the crank with a uniform motion, the disk is made to vibrate, and the steel point presses upon the tinfoil in the groove, leaving upon it a series of minute indentations.

In order to reproduce the words, the cylinder is turned back so that the steel point may go over the indentations made by speaking into the mouth-piece.

On turning the crank again, the point is made to work along the indentations in the groove. This sets the disk vibrating, and the vibrations, being communicated to the ear, reproduce the sound.

A funnel is generally inserted into the mouth-piece, to be used as an ear-piece when the sound is being reproduced.

Speech which has been recorded on the tinfoil may be kept for an indefinite period.

261. Energy of Sound Vibrations.—In order to make a body vibrate force must be applied to it. It then exhibits energy of motion, or kinetic energy, and this energy is transmitted to other bodies in its vicinity.

If a bow be drawn across the wire of the Sonometer, the force thus applied causes it to vibrate with an energy which is proportional to the square of the amplitude of the vibrations.

The vibrating body will come to rest when all its energy has been imparted to the surrounding bodies. This conduction varies according to the nature of the substance in contact with it; some bodies conveying away the energy much quicker than others.

If a tuning-fork is set vibrating, and the stem rested on a table, it will not vibrate so long as it would if the stem had been held between the thumb and finger.

Summary. —

Optical Study of Sounds.

Lissajous' Representation of Vibrations.

Experiments with Tuning-Fork.

Vibratory Motions at Right Angles.

Lissajous' Figures produced by Pendulum.

Kaleidophone.

Description of Koenig's Apparatus.

Mode of Operation.

Musical Instruments.

Stringed Instruments.

Sound from Pipes.

Pipes with Fixed Mouth-pieces.

Reed Pipes.

Wind Instruments.

Sounding Flames.

Sensitive Flames.

The Human Voice.

The Human Ear.

The Phonograph.

Description.

Mode of Operation.

Energy of Sound Vibrations.

CHAPTER VII.

HEAT.

SECTION I. — GENERAL PROPERTIES OF HEAT.

262. **Definition of Heat.** — Heat is the physical agent that produces the sensation we call warmth; the term *heat* is also applied to the sensation itself.

263. **Nature of Heat.** — We can regard heat as *molecular energy of motion*, or *molecular kinetic energy*. This motion consists of very rapid vibrations, or oscillations, of the molecules of a substance. Those bodies are hottest whose molecules vibrate with the greatest velocity and through the greatest amplitudes.

The term *cold* is used as a convenient term to express *diminution of heat*, but not the *entire absence of it*, for no substance is supposed to be wholly devoid of heat, and hence the molecules of every body are presumed to be in continual motion at all times and under all circumstances.

This energy of motion may be transmitted from one body to another through an elastic medium called *ether*, that pervades all matter and infinite space, in the same way that sound is transmitted through the air, that is, by means of waves.

Heat, then, since it can pass from one body to another or be kept in a body for any time, is a *measurable quantity*.

The *emission*, or *caloric*, theory supposes it to be a *substance*, a fluid destitute of weight, capable of passing from one body to another with great velocity. Its particles repel one another, and therefore oppose the attractive force of cohesion. The entrance of this substance into our bodies produces the sensation of warmth; its egress, the sensation of cold.

This theory is now generally discarded in favor of the one already given, which is called the *undulatory*, or *wave* theory. The latter affords a better explanation of the phenomena of heat, and at the same time serves to show the intimate relation between heat and light.

We shall also see, further on, that heat may be transformed into something which is not a substance at all, namely, mechanical work.

264. General Effects of Heat. — Heat may act on a body in three ways. One portion may be expended in promoting the warmth of the body, that is, by increasing the energy of motion of the vibrating molecules. A second portion acts as a repellent power, counteracting the force of cohesion and enlarging the amplitude of the molecular vibrations. This latter action causes an increase in the volume of the body, or completely alters the relative position of the molecules and produces a change of state; as when a solid is changed into a liquid, or a solid or liquid into a gas or vapor.

These two effects may be classed under the head of *internal work.*

The third portion is required to overcome the external pressure of the atmosphere, which must be forced back so that the body may expand.

This may be called *external work.*

When the body cools, the force of cohesion which was overcome by the repellent force of the heat, now reasserts its power and draws together the molecules. Hence we say that heat *expands* bodies, and cold *contracts* them.

265. Expansion of Bodies by Heat. — All bodies are expanded by heat, but in very different degrees. As a general rule, the most expansible bodies are gases, then liquids, and lastly solids.

In solids, which have definite figures, we have three kinds of expansion, — *linear expansion*, that is, expansion in length; *superficial expansion*, or expansion in two dimensions; *cubical*, or *volume*

expansion, that is, expansion in three dimensions. As a matter of fact, however, no one of these takes place without the other. As liquids and gases have no definite forms, expansion of volume is alone applicable to them.

266. Expansion of Metals. — Fig. 187 represents the method of showing and measuring the linear expansion of the metals by means of an instrument called the *pyrometer*. A rod of metal, *A*, passes through two metallic supports, being made fast at one extremity by a clamp-screw, *B*, and being free to expand at the other extremity. The free end abuts against the short end, *C*, of a lever, the long end, *D*, of which plays in front of a graduated arc.

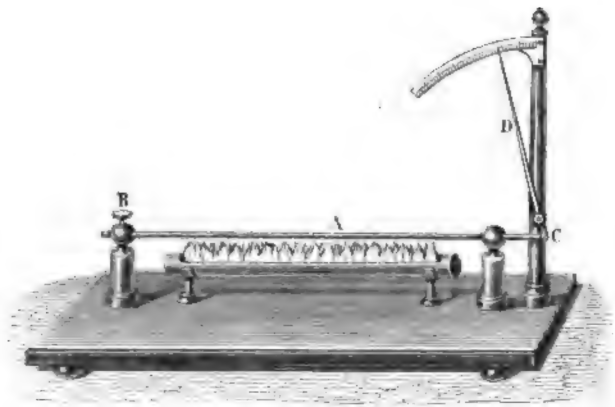


Fig. 187.

When the rod is heated, by placing fire beneath it, as shown in the figure, the rod, *A*, expands, and the expansion is shown by the motion of the index, *D*. When the rod, *A*, is of steel, copper, silver, etc., the amount of expansion varies, as is shown by the different amounts of displacement of the index. Brass, for example, expands more, for the same amount of heat, than iron or steel.

Fig. 188 shows the method of demonstrating that bodies undergo an expansion in volume when heated. A ring, *A*, is constructed so that a ball, *B*, passes freely through it when cold. If the ball be heated in a furnace, it will no longer pass through the ring; but if

allowed to cool, it again falls through the ring. The method of making the experiment is fully shown in the figure.

267. Unequal Expansion of Metals. — In Fig. 189 we have shown a simple contrivance for illustrating the unequal expansion of different metals. Two bars of iron and brass are riveted together at different points along their whole length, forming one compound bar.

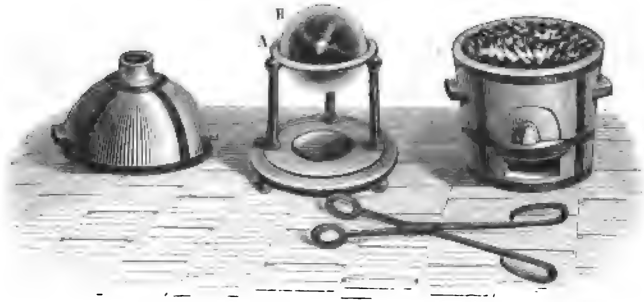


Fig. 188.

When such a bar is heated, the brass expands more than the iron, and the bar curves, as represented in Fig. 189, in order to accommodate the inequality of length which thus results. When the bar has returned to its original temperature, it assumes its rectilinear form, to bend again in the opposite direction if it be afterwards subjected to cooling. The unequal expansion of different metals is also shown in the compensation pendulums, pages 58, 59.

Fig. 189.

268. Expansion of Liquids and Gases. — Liquids and gases being more expansible than solids, their expansion is more easily shown by experiment. For liquids, we take a hollow glass sphere, terminating in a narrow tube, open at the top, and fill the globe and a portion of the stem with some fluid like mercury, as shown in Fig. 190. If heat be applied to the globe, the liquid will rise in the stem from *a* towards *b*, indicating an increase of volume; and if sufficient heat be applied, the liquid will fill the stem, and

will ultimately be converted into vapor. If the liquid is allowed to cool, it again returns to its original volume.

Fig. 190.

Fig. 191.

An analogous experiment shows the expansion of gases and vapors. A bulb of glass is provided with a long and fine tube of the same material, which is bent twice upon itself, as shown in Fig. 191. An index of mercury is introduced into the stem in the following manner. The bulb is heated, and a portion of the air which it contains is driven out, when a drop of mercury is poured into the funnel, *a*. If the instrument is allowed to cool, the air in the bulb contracts, and the pressure of the atmosphere drives the drop of mercury along the tube to some position, *m*.

The instrument having been prepared in this manner, if the bulb is held in the hand for a few minutes, the air becomes heated and expands, the expansion being indicated by the index moving to some new position, as *n*. If allowed to cool, the index returns to *m*.

Summary.—

Definition of Heat.

Nature of Heat.

The Undulatory, or Wave Theory of Heat.

The Emission, or Caloric Theory of Heat.

General Effects of Heat.

Internal Work.

External Work.

Heat expands Bodies.

Cold contracts Bodies.

Expansion of Bodies by Heat.

Expansion of Metals.

Expansion of Bodies by Heat (continued).
Experiments.
Unequal Expansion of Metals.
Expansion of Liquids and Gases.
Experiments.

SECTION II. — TEMPERATURE. — THE THERMOMETER.

269. Temperature. — The *temperature* of a body is that property that gives it the power, to a greater or less extent, of imparting *sensible* heat to other bodies.

By the term *sensible* heat is meant that portion of heat that increases the warmth of the body.

When one body gives off sensible heat to another, the former is said to have a higher temperature than the latter, or to be warmer.

The *temperature* of a body must not be confounded with the *quantity* of heat it possesses; a body may have a high temperature and yet have a very small quantity of heat, a low temperature and a large amount of heat. Quantity of heat will be treated of under the subject of *Specific Heat.*

270. The Thermometer. — A THERMOMETER is an instrument for measuring temperatures.

Our bodily sensations cannot serve as a sure guide in measuring temperature. A body may seem hot and cold to the same person at the same time. If we place one hand into pulverized ice and the other into water at about 100° F., and, after allowing them to stay awhile in this position, plunge them simultaneously into water at 70°, the hand from the ice will feel warm, but the one from the hot water will experience a sensation of cold.

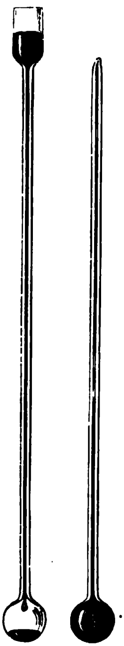
We must have a more accurate and constant standard of reference, and this is found in the thermometer.

The thermometer depends upon the principle that bodies expand when heated, and contract when cooled. Thermometers have been constructed of a great variety of materials. For common purposes,

the mercurial thermometer is preferred, on account of the uniformity with which both mercury and glass expand when heated.

It consists of a bulb of glass, at the upper extremity of which is a narrow tube of uniform bore, hermetically sealed at its upper end. The bulb and a part of the tube are filled with mercury, and the whole is attached to a frame on which is a scale for measuring the rise and fall of the mercury in the tube.

271. Method of making a Thermometer. — A capillary tube of glass is provided, of uniform bore, upon one end of which a bulb is blown, and upon the other a funnel, as shown in Fig. 192.



Figs. 192, 193.

The funnel is nearly filled with mercury, which is at first prevented from penetrating into the bulb by the resistance of the air and the smallness of the tube. The bulb is therefore heated, when the air within expands, and a portion escapes in bubbles through the mercury. On cooling, the pressure of the external atmosphere forces a quantity of mercury through the tube into the bulb. By repeating this operation a few times, the bulb and a portion of the tube are filled with mercury.

The whole is then heated till the mercury boils, thus filling the tube, when the funnel is melted off and the tube hermetically sealed by means of a jet of flame urged by a blow-pipe. On cooling, the mercury descends to some point of the tube, as shown in Fig. 193, leaving a vacuum at the upper end. It only remains to graduate it, and attach a suitable scale.

272. Method of Graduation. — Two points of the stem are first determined, the *freezing* and the *boiling points*. These are determined on the principle that the temperatures at which distilled water freezes and boils are always constant, that is, when these changes of state take place under equal atmospheric pressures.

The instrument is first plunged into a bath of melting ice, as shown in Fig. 194, and is allowed to remain until it takes the tem-

perature of the mixture, say twenty or thirty minutes. A slight scratch is then made on the stem at the upper surface of the mercury, and this constitutes the *freezing-point.*

The instrument is next plunged into a bath of distilled water, in a state of ebullition, care being taken to surround it with steam by

Fig. 194.

Fig. 195.

means of an apparatus like that shown in Fig. 195. After the mercury ceases to rise in the tube, which will be in a few minutes, the level of its upper surface is marked on the stem by a scratch, as before, and this constitutes the *boiling-point.*

The space between the boiling and freezing points is then divided

into a certain number of equal parts, and the graduation is continued above and below as far as may be desired. These divisions may be scratched upon the glass with a diamond, or, as is usually done, they may be made on a strip of metal, which is attached to the frame. The divisions are numbered according to the kind of scale adopted.

273. Thermometric Scales. — Three principal scales are used: the *Centigrade scale*, in which the space between the freezing and boiling points is divided into 100 equal parts, called *degrees; Réaumur's scale*, in which the same space is divided into 80 equal parts, called *degrees;* and *Fahrenheit's scale*, in which this space is divided into 180 equal parts, also called *degrees.*

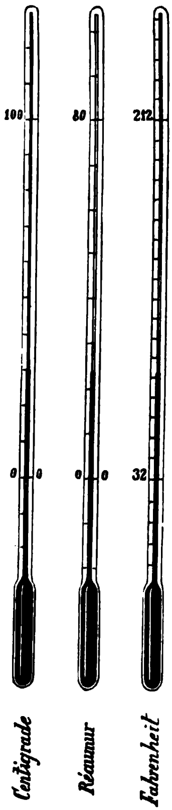


Fig. 196.

In the centigrade scale, the freezing-point is marked 0, and the degrees are numbered both up and down, the former numbers being considered positive, and designated by the sign +, whilst the latter are considered negative, and designated by the sign −. Of course the boiling point is marked 100°.

The signs + and — are used also in Réaumur's and Fahrenheit's thermometers to indicate degrees respectively above and below the zero point.

In Réaumur's scale, the freezing-point is marked 0, and the boiling-point 80°. The degrees below freezing are marked as in the centigrade scale.

In Fahrenheit's scale, which is the one principally used in the United States, the zero point is taken 32° below the freezing-point, and the divisions are numbered from this point both up and down. The boiling-point of distilled water is 212°.

Fig. 196 represents the thermometric scales, with the freezing and boiling points indicated upon them.

It is usual, in stating temperatures, to indicate the scale referred to by the initial letters F., C., R.

274. Conversion of Centigrade and Réaumur's Degrees into Fahrenheit's. — A degree on the centigrade scale is equal to one and eight tenths of a degree on the Fahrenheit scale, and one on Réaumur's scale is equal to two and a quarter on Fahrenheit's. Hence, to convert the reading on a centigrade to an equivalent one on Fahrenheit's scale, multiply it by 1.8 and add to the result 32°. Thus, a reading of 25° centigrade is equivalent to $25° \times 1.8 + 32°$, or 77° F. To convert a reading on Réaumur's scale to an equivalent one on Fahrenheit's, multiply by $2\frac{1}{4}$, and to the result add 32°. Thus, a reading of 24° Réaumur is equivalent to $24° \times 2\frac{1}{4} + 32°$, or 86° F.

By reversing the above processes, readings on Fahrenheit's scale may be converted into equivalent ones on the centigrade or Réaumur's scale.

The rules for the conversion of the three thermometric scales may be summed up in the following formulæ, in which F, C, and R denote equivalent temperatures expressed in degrees of the three scales: —

$$F = \tfrac{9}{5}\,C + 32 = \tfrac{9}{4}\,R + 32 \qquad (1)$$
$$C = \tfrac{5}{4}\,R = \tfrac{5}{9}\,(F - 32) \qquad (2)$$
$$R = \tfrac{4}{5}\,C = \tfrac{4}{9}\,(F - 32) \qquad (3)$$

275. Alcohol Thermometers. — An ALCOHOL THERMOMETER is similar to a mercurial one in all respects, except that alcohol, tinged red, is used in place of the mercury.

Because alcohol does not expand regularly with a regular increase of temperature, the alcohol thermometer has to be graduated by experiment, comparing it degree by degree with a standard mercurial thermometer. The degrees, in fact, increase in length as we ascend on the scale.

An alcohol thermometer is more easily filled than a mercurial one, no funnel being required. The bulb is heated until a portion of the contained air is driven off, and then the open end of the tube is plunged into a vessel of alcohol. As the air in the bulb cools, the

pressure of the external atmosphere forces a portion of alcohol up into the bulb. If this be boiled, the vapor of alcohol will expel the remainder of the air, and by dipping the open end of the tube into the alcohol once more, the bulb will be completely filled, when it again becomes cool. The instrument is then treated like the mercurial thermometer.

276. Relative Advantages of Mercurial and Alcohol Thermometers. — For ordinary purposes, the mercurial thermometer is to be preferred, on account of the uniformity with which the mercury expands with a uniform increase of temperature. But mercury congeals at 39° below 0 of the Fahrenheit scale, and where a lower temperature than this is to be observed, it becomes absolutely necessary to employ the spirit thermometer. In the severe cold of the polar regions, mercury often congeals, but no degree of cold has yet been obtained that will congeal absolute alcohol.

For high temperatures, mercury only is capable of being used: this liquid does not boil till raised to 662° F., whilst alcohol boils at 174° F. The latter liquid cannot therefore be used to observe temperatures higher than 174° F., nor can it be relied upon even for temperatures considerably lower than this.

It is to be observed that mercury cannot be relied upon for temperatures lower than 32° below 0, on account of irregularities in its rate of contraction below that limit.

Alcohol has also the disadvantage of being slower in its action than mercury, on account of its inferior conducting power.

277. Rules for using a Thermometer. — Before noting the height of the mercurial column, the instrument should be allowed to acquire the temperature of the medium in which it is placed. This, in general, will require some minutes.

In determining the temperature of a room, the thermometer should not be hung against the walls, but should be freely suspended, so as to take the temperature of the atmosphere. When hung against a wall, especially an outer wall, an error of several degrees may result. In like manner, if hung against a wall containing a flue, or adjoining another room of different temperature, a similar error of several degrees might result.

To determine the temperature of the atmosphere, the thermometer should be freely suspended in the air, at some distance from any building or tree. It should be sheltered from the direct action of the sun's rays, as well as from the influence of reflecting substances. Furthermore, it should be protected from winds and currents of air.

278. The Differential Thermometers. — A DIFFERENTIAL THERMOMETER is a thermometer contrived to show

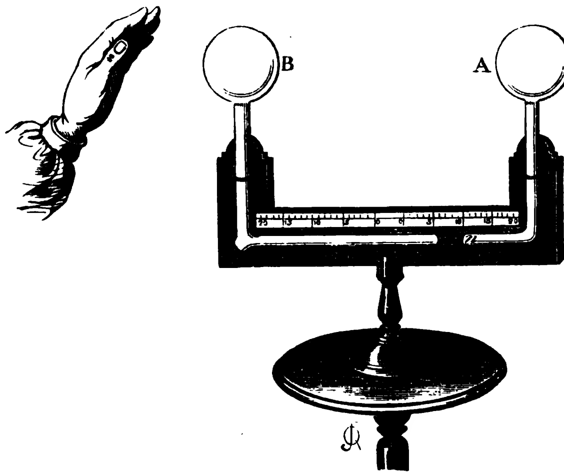


Fig. 197.

the difference of temperature between two places near each other. The two principal forms of the differential thermometer are RUMFORD'S and LESLIE'S.

They are based on the expansion of air, and are, therefore, *air thermometers.* These instruments are not affected by the varying pressure of the atmosphere, as many air thermometers, and are, consequently, less inaccurate.

279. Rumford's Differential Thermometer. — RUMFORD'S DIFFERENTIAL THERMOMETER is represented in Fig. 197.

It consists of two bulbs of thin glass, A and B, connected by a fine tube bent twice at right angles, as shown in the figure. The whole apparatus is attached to a suitable frame, which supports a scale parallel to the horizontal branch of the connecting tube. The 0 of the scale is at its middle point, and the graduation is continued from it in both directions. The bulbs and a large part of the connecting tube are filled with air; there is, however, in the tube a small drop of fluid which separates the air in the two extremities.

The instrument is so constructed that the index n is at the 0 of the scale when the temperature of the two bulbs is the same. When one of the bulbs is heated more than the other, the air in it expands and drives the index towards the other, until the tensions of the air in the two bulbs exactly balance each other.

The scale is divided by experiment by the aid of a standard mercurial thermometer.

280. Leslie's Differential Thermometer. — LESLIE'S DIFFERENTIAL THERMOMETER is shown in Fig. 198. It differs from RUMFORD'S in having the bulbs smaller, and in containing a longer column of liquid in the tube. The scales are placed by the sides of the vertical portions of the tube, having their 0 points at the middle. There is, then, a double scale. The method of graduating and using this thermometer is the same as that described in the last article.

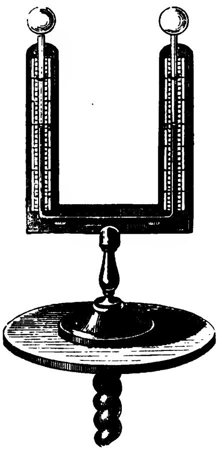


Fig. 198.

But of all instruments for detecting and measuring slight differences of temperature, the most delicate and accurate is the *thermo-electric pile,* which will be described hereafter.

281. Pyrometer. — A PYROMETER is an instrument for measuring higher temperatures than can be observed by means of the mercurial thermometer.

The most important pyrometers are those of WEDGEWOOD and BROGNIART. The former is founded on the diminution of the volume of clay at high temperatures, and the latter (Fig. 187) on the principle of the expansion of metals. The indications of these instruments are very untrustworthy, and they have gone substantially out of use.

The arrangements now used for measuring the higher temperatures are based on the expansion of gases and vapors, or on the electrical properties of bodies.

282. Absolute Zero of Temperature. — Since a gas expands for each degree centigrade $\frac{1}{273}$ of its volume at 0°, it follows that at a temperature of 273° C. its volume is doubled, and that the amount of contraction when the temperature is reduced to — 273° would be equal to the initial volume. The gas then would be reduced to a mathematical point, and would cease to exist.

This point on the centigrade scale is called the *absolute zero of temperature*, and temperatures reckoned from this point are called *absolute temperatures*. The lowest temperature that can thus be expressed is evidently — 273° C. or — 460° F. We can obtain absolute temperatures by adding 273 to the temperature on the centigrade scale, or 460 to that on the Fahrenheit.

An absolute zero of heat has never yet been realized experimentally. Even if matter can exist without heat, which there is great reason to doubt, it is impossible to predict what would be its condition under such circumstances.

If the energy of motion, which we call heat, should wholly cease exerting its power, and the molecules be brought into actual contact, phenomena of a new and unexpected character would undoubtedly result.

The artificial cold of —140° C., or —220° F., was produced by Naterer. The greatest natural cold recorded in Arctic expeditions is —58.7° C., or —73.66° F.

Summary. —

Temperature of Bodies.
Definition of the Term *Temperature.*
Definition of Sensible Heat.
Distinction between Temperature and Quantity of Heat.

The Thermometer.
Definition of a Thermometer.
Untrustworthy Results of Bodily Sensations.
Principle upon which it depends.
Method of making a Mercurial Thermometer.
Method of graduating a Mercurial Thermometer.

Thermometric Scales.
Centigrade.
Réaumur.
Fahrenheit.
Conversion of one Scale into Another.

Alcohol Thermometers.
Relative Advantages of Mercurial and Alcohol Thermometers.
Rules for using a Thermometer.

Differential Thermometers.
Rumford's.
Leslie's.

Absolute Zero of Temperature.

SECTION III. — LAWS OF EXPANSION OF SOLIDS, LIQUIDS, AND GASES.

283. **Law of Expansion of Solids.** — Numerous experiments have been made to determine the exact amount of expansion which bodies experience by the addition of a given amount of heat. As in a former article, it will be found convenient to consider, first, *linear expansion*, and afterwards, *expansion in volume.*

1. *Linear Expansion.* — In order to compare the rate of linear expansion of different bodies, we take, for a term of comparison, the expansion experienced by a unit of length

of each body when heated from 32° F. to 33° F. This is called *the coefficient of linear expansion.*

The coefficients of linear expansion for a great number of bodies were determined in the latter part of the last century by Lavoisier and Laplace. They reduced the substance to be experimented upon to the form of a rod or bar, then exposed it for a sufficient time to the temperature of melting ice, and measured its exact length. They next exposed the bar to a temperature of boiling water, and again measured its length. The increased length, divided by 180, gave the increase in length of the whole bar for 1° F. This result, divided by the length of the bar at 32° F., gave the linear expansion of a unit of length, and for an increase of temperature of 1° F., that is, *the coefficient of linear expansion.*

The following are some of the latest results: —

Substance.	Coefficient for 1° F.	Substance.	Coefficient for 1° F.
Glass . . .	0.00000474	Brass . . .	0.00001044
Platinum . .	0.00000483	Copper . . .	0.00000957
Steel	0.00000631	Silver . . .	0.00001068
Iron	0.00000665	Lead	0.00001565
Gold	0.00000800	Zinc	0.00001653

From the above table, it is seen that the amount of expansion is always very small.

2. *Expansion in Volume.* — The *coefficient of expansion in volume* is the increment which a cubic unit of the substance experiences when its temperature is raised 1° F. This coefficient may be determined experimentally, or it may be found by multiplying the coefficient of linear expansion by three. The superficial expansion of a solid is, of course, twice as great as the linear expansion.

284. Applications. — The principle of expansion explains many familiar phenomena, some of which we will give.

A cold tumbler is often broken when it is suddenly filled with hot

water. The explanation is simple. Glass is a bad conductor of heat, hence the inside becomes heated by contact with the water more rapidly than the outside, and this inequality of heating produces an inequality of expansion that ruptures the glass. The thinner the glass, the less will be the inequality of expansion, and consequently the less will be the danger of rupture. In a metallic vessel such an accident is not to be apprehended, because metals are good conductors, and but little, if any, inequality of expansion can arise.

When a candle is held too near a pane of glass, the glass is often broken; the reason is the same as before. Sometimes a glass vessel is broken by suddenly opening a door or window. This is due to a current of cold air, which, falling upon the outer surface of the glass, causes an inequality of contraction that may produce rupture. All articles of glass should be guarded from sudden changes of temperature, if we would avoid risk of breakage.

In the art of engineering, it is important to take into account the expansion and contraction of the metals. In laying the track of a railroad, for example, the rails should not be laid so as to touch each other, otherwise in warm weather the expansion, acting through a long line, might produce a force sufficient either to bend the rails or to tear them from their fastenings. In employing iron ties in building, arrangements should be made by means of nuts and screws to tighten them in warm weather, and loosen them in cold weather, otherwise the forces of contraction and expansion would weaken and eventually destroy the building. Very serious accidents have occurred from omitting this precaution.

The principle of expansion and contraction of metals has been utilized in bringing the walls of a building together after they have commenced to separate. A system of iron ties is formed, passing through the opposite walls, on the outside of which they are secured by nuts. The alternate rods being heated, they expand, and the nuts are screwed up close to the walls. On cooling, the force of contraction brings the walls nearer together. The remaining rods are next heated, and the nuts screwed up. On cooling, a further contraction takes place, and so on until the walls are restored to their proper position. This method was successfully employed to restore the walls of a portion of the Conservatoire des Arts et Metiers, in Paris, which had begun to separate.

There are some apparent exceptions to the law that heat expands bodies and cold contracts them. Thus, bodies capable of absorbing water, like paper, wood, clay, and the like, contract on being heated. This contraction is only apparent; it arises from the water which they contain being vaporized and driven off, which produces an apparent diminution of volume; after they are thoroughly dried, they follow the general law, with the exception of clay. This contracts permanently, by reason of chemical changes among its particles.

The property just explained is used for bending absorbent bodies. To effect this they are heated on one side only, which drives out the water from that side, and causes them to bend in that direction. It is this principle that causes wooden articles to warp, and therefore demands that articles of furniture and wooden parts of buildings be coated with oils, paints, or varnishes, to prevent the absorption of water.

The principle of expansion and contraction is often utilized in the arts. A familiar example is the process of setting the tire of a wagon-wheel. The tire is made a little smaller than the outer periphery of the wooden part of the wheel. It is then heated, and placed around the wheel; on cooling, it contracts powerfully, and draws the felloes firmly together.

285. Law of Expansion of Liquids. — Liquids are much more expansible than solids, on account of their feeble cohesion; their expansion is also much more irregular, especially when their temperature approaches the boiling-point.

The expansion of a liquid may be *absolute* or *relative*. The absolute expansion of a liquid is its actual increase of volume; the relative expansion is its increase of volume with respect to the containing vessel. For example, in a thermometer the rise of the liquid in the stem is due to its relative expansion with respect to that of the stem. Both expand, but the liquid more rapidly than the glass. The capacity of the bulb increases with an increase of heat, but the volume of its contained mercury increases more rapidly, and therefore rises in the stem. The absolute is usually

greater than the relative expansion. It is the relative expansion that we generally observe.

The *coefficient of expansion* of a liquid is the expansion of a unit of volume, corresponding to an increase of temperature of one degree.

Taken with reference to glass, the coefficient of expansion for mercury is 0.000833; that of water is three times as great, and that of alcohol nearly eight times as great as that of mercury.

286. Maximum Density of Water. — If water is cooled down gradually, its volume continues to contract until it reaches the temperature of 39.2° F., or 4° C., when it attains its maximum density. If it be still further cooled, it begins to expand, and at 32° F., or 0° C., it becomes solid, or *freezes*.

This curious phenomenon may be shown by using a water thermometer in connection with a mercurial one. As the temperature is diminished, the liquids descend in the stems of both thermometers until the mercurial one shows 39.2° F., after which, if the cooling process be continued, the mercury will continue to fall, whilst the water will begin to rise.

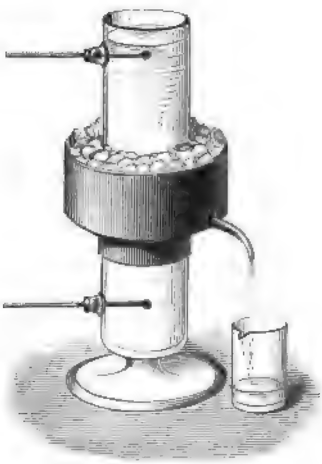


Fig. 199.

The maximum density of water can be determined more accurately by another method. We have represented in Fig. 199 a glass jar having two lateral openings, one near the top, and the other near the bottom. Into these apertures are inserted two thermometers. The jar is filled with water, and a freezing mixture placed around its central part. If the freezing mixture remains long enough about the jar, we shall have the following results.

The lower thermometer falls to 4° C., or 39.2° F., and remains at

that point. The upper one at first changes very little, but when it reaches the fixed temperature, it begins to fall until it sinks to the freezing-point, when the water at the surface freezes. The reason is this: as the water in the centre grows colder its density increases, and it falls to the bottom. This process goes on until all the water in the lower part of the vessel has reached the temperature of 39.2° F.

When this portion of the water has this temperature, circulation in it ceases, until needles of ice are formed, which, being lighter, rise to the surface and start up a new circulation, which causes the water to freeze at the surface, while that near the bottom remains at 39.2°.

This experiment proves that water is heavier at 39.2° than at 32°, since it sinks to the lower part of the vessel.

This apparent exception to the law of expansion and contraction is explained from the fact that at the temperature of 39.2° F. the particles begin to arrange themselves in a new order, preparatory to taking a crystalline form. Some other substances, such as melted iron, sulphur, bismuth, etc., exhibit a similar expansion of volume immediately previous to taking a solid crystalline form. It is this property of expanding at the time of crystallization that renders iron so valuable a metal for casting. The expansion of the metal acts to fill the mould, thus giving sharpness and accuracy to the casting.

The fact that water has its greatest density at 39.2° F. causes ice to form at the surface instead of at the bottom of rivers and lakes. Were it not that ice is lighter than water, it would sink to the bottom as fast as formed, or rather would form at the bottom, and in the colder regions of the globe would soon convert entire lakes into solid masses of ice. As ice and water are bad conductors of heat, the summer sun would not possess the power to convert them again into water.

In Switzerland it is found by experiment that the temperature of the water at the bottom of deep and snow-fed lakes remains during the entire year at the uniform temperature of 39.2° F., although the surface is frozen in winter, and in summer rises to 75° or 80° F.

It is because water has its maximum density at 39.2° F., that it

is taken at this temperature, as the standard of comparison for determining the specific gravity of bodies.

287. Law of Expansion of Gases. — Gases are not only more expansible than solids and liquids, but they also expand more uniformly.

The *coefficient of expansion* of a gas is the expansion which a unit of volume experiences when its temperature is increased one degree.

GAY-LUSSAC supposed that all gases expand equally for equal increments of temperature; but more recent investigations show that the coefficients of expansion are slightly different for different gases. This difference is, however, so small that for all practical purposes we may regard all gases as having the same coefficient. The value of the coefficient of expansion for gases is 0.00204, which is about eight times that of water.

288. Applications. — The law of expansion of gases, when heated, has many important applications, some of which will be explained.

When the air of a room becomes warmed and vitiated by the presence of a number of persons, it expands and becomes lighter than the external air; hence it rises to the top of the room, and its place is supplied by fresh air from without, which enters through the cracks of the doors, or through apertures constructed for the purpose. Openings should be made at the upper part of the room to permit the foul air to escape. Such is the theory of *ventilation* of rooms.

In large buildings, like theatres, the spectators in the upper galleries often experience great inconvenience from the hot and corrupt air arising from below. To remedy this evil, large openings, called ventilators, should be constructed in the ceiling, and corresponding openings should be arranged near the bottom of the building to supply a sufficient quantity of fresh air to keep up the circulation.

The principle of expansion gives a draught to our chimneys. The hot air ascends through the flue, and its place is supplied by a continued current of cold air from below, which keeps up the combustion in the fireplace or grate.

The same principle is applied in warming buildings by means of furnaces. Furnaces are placed in the lowest story of the building, and are provided with air-chambers, which communicate with the external air by means of air-pipes. When the air becomes heated in the air-chamber, it rises through pipes, or flues in the walls, to the upper stories of the building, and is admitted to or excluded from the different apartments by valves, called *registers*.

The principle of expansion of air explains many meteorological phenomena. When the air in any locality becomes heated by the rays of the sun, it rises, and its place is supplied by colder air from the neighboring regions, thus producing the phenomena of winds. The circulation of the atmosphere in the form of winds tends to equalize the temperature, and also, by transporting clouds and vapors, tends to equalize the distribution of water over the globe.

Winds also serve to remove the vitiated air of cities, replacing it by the pure air of the neighboring places, thus contributing to the preservation of life and health. Winds also act to propel vessels on the ocean, thus contributing to the spread of commerce and civilization.

Without winds, our cities would become centres of infection, the clouds would remain motionless over the localities where they were formed, the greater portion of the earth would become arid and desert, without rivers or streams to water them, and the whole earth would soon become uninhabitable.

289. Density of Gases. — The density of a gas depends upon the pressure to which it is subjected, and also upon its temperature.

It is for this reason that we select as a term of comparison the density at some particular pressure and temperature. The standard pressure is that of the atmosphere when the barometer stands at 30 inches, and the standard temperature is 32° F., or the freezing-point of water. To determine the density at any other pressure, we apply MARIOTTE'S law; to determine it at any other temperature, we apply the coefficient of expansion, as explained in preceding articles.

Suppose it were required to determine the density of air when the barometer indicates 20 inches, and the thermometer 62° F., the

density being equal to 1 at the standard temperature and pressure. The pressure being only two thirds the standard pressure, the air in the case considered would occupy once and a half its primitive volume, supposing the temperature to remain at 32° F. But the temperature being 62° F., or 30° above the standard, we multiply 1.5 by 30 times 0.00204 for the expansion. This product, added to 1.5, gives for a result 1.5918. That is, a unit of volume at the standard pressure and temperature becomes 1.5918 units of volume at the given pressure and temperature. Because the density varies inversely as the volume, we shall have for the required density $\frac{1}{1.5918}$, or 0.6282.

The following table exhibits the density of some of the most important gases, air being taken as a standard: —

Gas.	Density.	Gas.	Density.
Air	1.0000	Oxygen . .	1.1056
Hydrogen . ..	0.0692	Carbonic acid .	1.5290
Nitrogen . .	0.9714		

Hydrogen is the lightest known body, its density being fourteen and a half times less than that of air.

Summary. —

Law of Expansion of Solids.

Coefficient of Linear Expansion.

Coefficient of Expansion in Volume.

Practical Applications of the Principle of Expansion.

Law of Expansion of Liquids.

Absolute and Relative Expansion.

Coefficient of Expansion.

Maximum Density of Water.

Experiments.

Apparent Exceptions to the Law of Expansion and Contraction.

The Freezing of Lakes and Ponds.

Law of Expansion of Gases.

Coefficient of Expansion.

Practical Applications of the Expansion of Gases.

Density of Gases.

SECTION IV. — DIFFUSION OF HEAT.

290. Methods of Diffusion.—There are three methods of diffusing heat, — *Radiation*, *Conduction*, and *Convection*. We shall find in another article that diffusion of heat invariably transfers heat from a hotter body to a colder one, so as to cool the hotter and warm the colder. The three methods will now be considered in the order named.

291. Radiation of Heat. — The ethereal medium that transmits heat extends through space, and is almost perfectly elastic. It penetrates all bodies and occupies the intervals between their molecules. The heat vibrations of bodies are thus imparted to the surrounding ether, and by it are propagated outward in spherical waves similar to sound-waves in air. Heat propagated in this way is called *radiant heat*. A line perpendicular to a wave front is called a *ray of heat*.

A ray of heat indicates a *direction* in which heat is propagated and along which it produces its effect. In a homogeneous medium heat-rays are straight lines radiating in every direction from a heated body. Radiant heat does not impart warmth to the medium that transmits it, but when intercepted by a body the molecular energy of the ether is imparted to the molecules of the body, and the phenomena of heat are developed.

When we speak of radiant heat, it must be understood that it is not a *new* kind of heat, but radiation considered in its thermal, or heat aspect.

In order to distinguish it from the ordinary heat-energy which bodies possess, it may be regarded as *undulatory*, or *radiant* energy which travels through space with great velocity; and when rays of heat, as has been stated, are intercepted by a body, this radiant energy is changed to ordinary heat-energy, which in turn is changed back again into radiant energy when heat is given off by any substance.

292. Laws of Radiant Heat. — The radiation of heat takes place according to the following laws: —

1. *Heat is radiated equally in all directions.*

This law may be verified by placing thermometers at equal distances and in different directions from a heated body.

2. *Rays of heat are straight lines.*

This law may be verified by interposing a screen anywhere in a right line joining the heated body and the thermometer, when the thermometer will cease to rise.

If a ray pass from one medium to another, it is bent from its course; this bending is called *refraction.*

We see refraction of heat when the luminous thermal rays of the sun, like the rays of light, are refracted to a focus by a converging lens. Non-luminous rays of heat, or obscure rays, as they are generally called, can be refracted by a lens of rock salt held before an iron ball heated below redness.

The laws of refraction for heat are the same as for light, and will be more fully discussed under that subject.

3. *The intensity of radiant heat varies directly as the temperature of the radiating body, and inversely as the square of the distance to which it is transmitted.*

The first part of this law is verified by exposing one of the bulbs of a differential thermometer to a blackened cubical box, filled with hot water, the other bulb being protected by a screen. If the water is in the first instance of a given temperature, and then falls to a half or a third of that temperature, the differential thermometer will manifest a half or a third of its original indication, and so on for any temperature.

The second part of the law may also be verified by means of the differential thermometer. In this case the heated body is kept always at the same temperature, and one bulb of the differential thermometer is placed at different distances from it. It will be found that at a double distance the indication is only a fourth of the original indication, at a triple distance only a ninth, and so on.

4. *Radiant heat is propagated in a vacuum as well as in air.*

The radiation of heat from the sun to the earth proves this law.

It can be demonstrated also by the following experiment. In the bottom of a glass globe (Fig. 200) a thermometer, *t*, is sealed air-

tight, in such a manner that its bulb occupies the centre of the globe. The apparatus is then filled with mercury, and inverted over a cup of mercury with the end of the neck of the globe under the surface of the mercury. We get in this way a Torricellian vacuum.

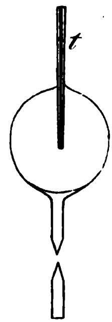


Fig. 200.

Now melt off the neck with a blow-pipe above the mercury. If the globe be immersed in hot water, the mercury is seen at once to rise. And this must be due to the radiation of heat through the vacuum.

293. Exchange of Heat between Bodies. —The process of radiation of heat between bodies is *mutual* and *continuous.* According to the laws given in the preceding article, those bodies which are most heated give off most heat; hence the hottest bodies of a group give off more heat than they receive, and the coldest ones receive more than they give off. The consequence is, that there is a continual tendency towards equalization of temperature. If all the bodies are of the same temperature, each will give off as much as it receives, and no further change of temperature can occur. The process of radiation, however, goes on as before.

All the bodies in a room, for example, tend to come to a uniform temperature. We say, tend to come to a uniform temperature, because this condition is never fully realized. Bodies nearest the walls are continually exchanging heat with the walls, and as these are in communication either with the outer air or with other rooms, their temperature will be influenced thereby, and will in turn exert an influence upon the remaining bodies in the room.

294. Reflection of Radiant Heat. —When radiant heat falls upon the surface of a body, some of it is deflected or bent from its course. This bending is called *reflection.*

The point at which the bending takes place is called *the point of incidence.* The ray before incidence is called *the incident ray;* after incidence, it is called *the reflected ray.* A line drawn perpendicular to the surface at the point of inci-

dence is called *the perpendicular.* The angle between the incident ray and the perpendicular is *the angle of incidence;* the angle between the perpendicular and the reflected ray is *the angle of reflection.* The plane of the incident ray and the perpendicular is the plane of incidence; the plane of the reflected ray and the perpendicular is the plane of reflection. These planes coincide.

295. Laws which govern the Reflection of Heat.—The following laws, indicated by theory, have been confirmed by experiment:—

1. *The plane of the incident and reflected rays is perpendicular to the reflecting surface at the point of incidence.*

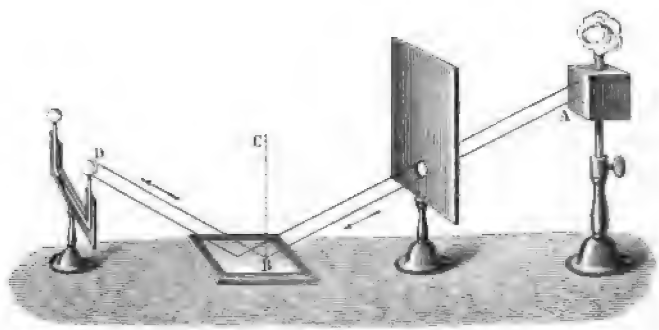


Fig. 201.

2. *The angles of incidence and reflection are equal.*

The apparatus employed in establishing these laws is shown in Fig. 201. *A* is a tin box with its faces blackened, in which hot water is placed. *B* is a reflecting surface, and *D* is a differential thermometer. *B C* is a perpendicular to the reflecting surface.

The surface, *A*, radiates heat in all directions, but only a single ray is permitted to fall upon the reflector, *B*, the remainder being intercepted by a screen, having a small hole in it. By suitably arranging the thermometer, and other parts of the apparatus, it may be shown that the plane *A B D* is perpendicular to the reflecting surface at *B*, and that the angles, *A B C* and *C B D*, are equal to each other.

296. Reflection of Heat from Concave Mirrors.— A CONCAVE MIRROR is a polished spherical or parabolic surface, usually of metal, employed to concentrate rays of heat at a single point.

It is a property of such mirrors that all rays which before incidence are parallel to the axis, are after reflection converged to a single point, which point is the *focus* of the mirror. Conversely, if the rays proceed from the focus, they will be reflected in lines parallel to the axis.

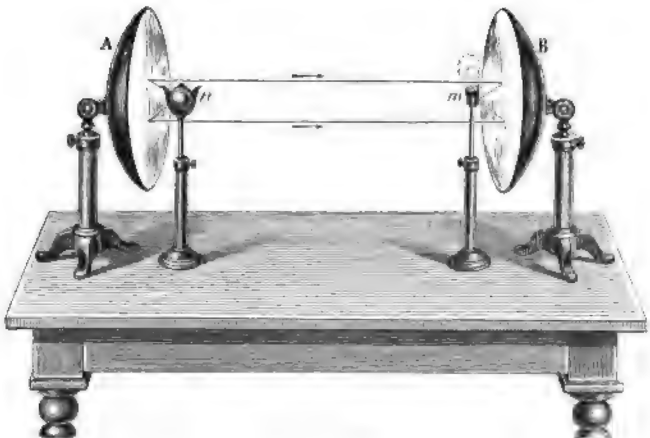


Fig. 202.

A and *B* (Fig. 202) represent two reflectors, having their axes coincident, and their surfaces turned to each other. In the focus, *n*, of the mirror, *A*, is placed a ball of hot iron, and in the focus, *m*, of the mirror, *B*, is placed an inflammable substance, as a piece of phosphorus. The heat radiating from the ball is reflected from *A*, parallel to the common axis of the mirror, and falling upon *B*, is again reflected to the focus *m*; the heat, concentrated at *m*, is sufficient to inflame the phosphorus, even when the mirrors are several yards distant from each other. If the mirror, *A*, alone is used, the phosphorus is not inflamed.

Parabolic reflectors brings parallel rays more accurately to a focus than spherical, but are more difficult to construct, and therefore are not used so much.

The property of concave mirrors, above explained, enables us to concentrate the heat of the sun's rays. In this case the reflector is called a *burning mirror.* It must be placed so that its axis is parallel to the rays of the sun, which, as they fall upon it, are reflected to the focus, where they produce heat enough to set inflammable substances on fire.

It is said that ARCHIMEDES was enabled by means of mirrors to set fire to the Roman ships in the harbor of the city of Syracuse. BUFFON showed the possibility of such an operation, by setting fire to a tarred plank, by means of burning mirrors, at a distance of more than 220 feet.

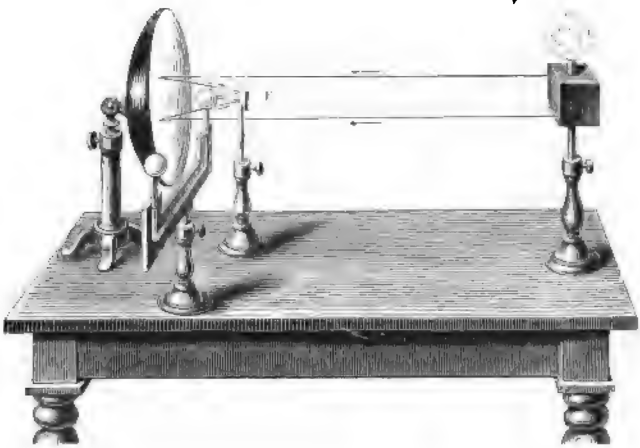


Fig. 203.

297. Reflecting Power of Different Substances. — Those bodies which reflect a large portion of the incident heat are called *good reflectors ;* those which reflect but little are called *bad reflectors.*

Fig. 203 shows the method of determining the relative reflecting powers of different bodies, adopted by LESLIE. He placed a cubical tin box, filled with water at the boiling-point, in front of a parabolic reflector. The rays of heat, falling upon the reflector, are reflected and tend to come to a focus at *F*, but by interposing a square plate of some sub-

stance between the mirror and its focus, the rays are again reflected, and come to a focus as far in front of the plate as F is behind it. The heat thus reflected is received upon one bulb of a differential thermometer, by means of which it is measured. By interposing plates of different substances in succession, their relative reflecting powers are determined.

In this way LESLIE showed that polished brass possessed the highest reflecting power; silver reflects only nine tenths, tin only eight tenths, and glass only one tenth as much as brass. Plates blackened by smoke do not reflect heat at all.

It has been stated that when radiant heat falls upon the surface of a body, some of it is reflected. There is some of it also that is absorbed by the body, and some transmitted.

A substance that transmits heat is called *diathermanous*, and one that does not, *athermanous*.

Rock salt is the most diathermanous of all solids. Radiant heat, both luminous and obscure, will pass through it with about the same facility that light passes through glass. Glass is very transparent, that is, will let light through it readily, but is not specially diathermanous.

Incident rays not transmitted are either reflected or absorbed. It is only the rays absorbed that warm a body.

298. Absorbing Power. — In order to determine the relative powers of absorption, LESLIE employed the apparatus shown in Fig. 204.

The source of heat and the reflector remaining as before, he placed the bulb of the differential thermometer in the focus of the reflector, covering it successively with layers of the substance to be experimented upon. In this way he showed that those substances which reflect most heat absorb least, and the reverse.

When the bulb was blackened by smoke, the thermometer indicated the greatest change of temperature, and when covered with leaves of brass, it indicated the least change.

299. Radiating Power. — The RADIATING POWER of a body is its capacity to *emit*, or *radiate* the heat which it contains.

In determining the radiating power, LESLIE employed the apparatus shown in Fig. 204. In this case, instead of covering the bulb of the thermometer with layers of the substances to be experimented upon, he covered the different faces of the cubic box with layers of the different substances.

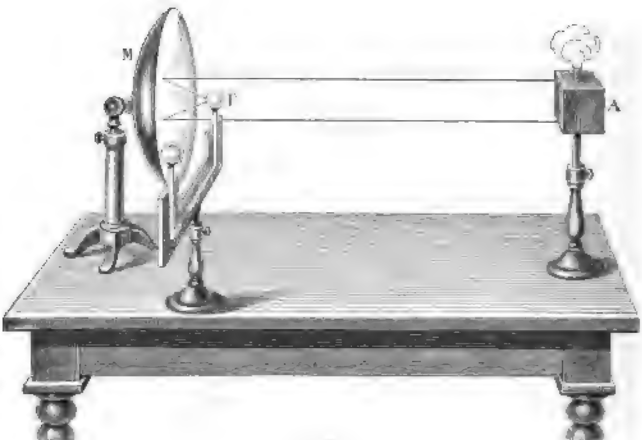


Fig. 204.

For example, let one face be made of tin, let a second be blackened by smoke or lamp-black, let a third be covered by a layer of paper, and a fourth by a plate of glass. On turning these different faces towards the reflector, the thermometer indicates different degrees of temperature. If the blackened face be turned towards the reflector, the thermometer rises, showing that this face is a good radiator; if the paper-covered face be next turned towards the reflector, the thermometer falls, showing that paper is a poorer radiator than lamp-black; if the glass-covered face be turned towards the reflector, the thermometer falls still lower, indicating that glass is a poorer radiator than paper; finally, if the tinned face is turned towards the reflector, the thermometer falls still lower, indicating the fact that tin is a poorer radiator than glass.

LESLIE found, by this course of proceeding, that the radiating powers of bodies are the same as their absorbing powers; that is, a good radiator is also a good absorber but a bad reflector, and the reverse.

It is commonly supposed that bodies of bright colors radiate heat to a less extent than those of a dull and dark color. This was disproved by Melloni, at least for *obscure* heat. He found that white lead and lamp-black radiated the same amount of heat.

300. Modifications of the Reflecting Powers of Bodies. — The principal causes that modify the reflecting and absorbing powers of bodies are: *polish*, *density*, *direction of the incident rays*, *nature of the source of heat*, and *color.*

Other things being equal, *polished bodies are better reflectors and worse absorbers than unpolished ones.*

Other things being equal, *dense bodies are better reflectors and worse absorbers than rare ones.*

Other things being equal, *the nearer the incident ray approaches the perpendicular, the less will be the portion reflected and the greater the portion absorbed.*

The nature of the source of heat sometimes modifies the reflecting and absorbing powers. Thus, if a body is painted with white lead, it absorbs more heat from a cubical box of boiling water, than though the same heat were emitted by a lamp. But if a body is painted with lamp-black, the amount absorbed is the same, whatever may be its source.

Light-colored bodies absorb less and reflect more heat than dark-colored ones. This is found to be true in regard to luminous heat, such as that of the sun. But in the case of obscure heat, color does not seem to affect the absorption.

Whether a body is a good reflector, absorbent, or radiator, or whether it is the reverse, depends more upon the molecular condition of its surface than upon its color.

301. The Radiometer. — This consists of a glass tube (Fig. 205) with a bulb blown in it, which rests on a wooden support. A fine steel point is fused on a small tube extend-

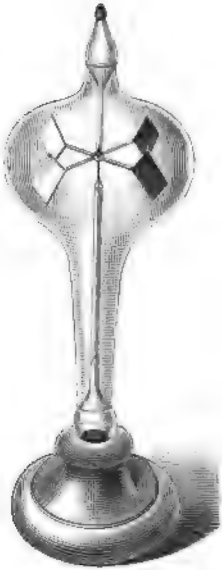


Fig. 205.

ing up into the bulb; on this point rests a small vane consisting of four arms, each one carrying a disk of mica or pith, white on one side and covered with lamp-black on the other.

In order to keep the vane on the steel pivot, a small tube extends down from the top of the bulb so as to surround the top of the cap, which rests on the pivot without touching it. The other end of this tube is drawn out, and connected with some apparatus for exhausting the air. When this is done, the bulb is hermetically sealed.

If a hot body be brought near the radiometer, or if it be exposed to the sunlight, the arms will rotate more or less rapidly. The cause of this was formerly supposed to be due to the mechanical action of light, but it is now thought to be owing to heat radiations, and the reactive force of the molecules of the rarefied gas in the bulb.

302. Absorbing Power of Gases. — The power of the different gases in absorbing heat varies greatly. The simple gases, hydrogen, oxygen, and nitrogen, absorb very little. Dry air also is a very poor absorbent. The aqueous vapor in the atmosphere, however, has great power of absorption; but it is more manifest in the case of obscure than luminous rays.

Some of the compound gases exhibit great capacity for absorbing dark heat, such as sulphurous acid and ammonia, the former absorbing nearly 900 times as much as dry air.

We shall see in another chapter that light is subject to the same laws that radiant heat is: viz., it is reflected, refracted, transmitted, and absorbed. They both undergo another modification, also, called polarization, to be explained hereafter.

In view of these facts, we are justified in our inference that heat and light are either identical or closely allied to each other.

303. Applications of the Preceding Principles. — Articles of clothing are intended to preserve uniformity of temperature in the human body by excluding the too violent heats of summer, and by preventing too rapid radiation of animal heat in winter.

Loose substances, like woollens and furs, are bad reflectors, and therefore are suitable for winter clothing. Compact substances, like linens and cottons, are good reflectors, and therefore are suitable for summer clothing.

Snow is a good reflector, but a bad absorber and radiator. Hence it is that a layer of snow in winter acts to protect the plants which it covers. Snow and ice, when exposed to the rays of the sun, melt but slowly; but if a branch of a tree or stone projects through the snow, it causes the latter to melt in its neighborhood, first by absorbing the heat of the sun, and then radiating it to the surrounding particles of ice or snow.

If a stone is thrown upon a field of ice, it soon causes the ice around it to melt, forming a hole into which it sinks. A dark cloth spread upon snow acts in the same manner, and soon sinks under the influence of the sun's rays.

Water is soonest heated in a vessel whose surface is black and unpolished, because the vessel in this state is best adapted to absorb the heat which is applied to it, but on removing it from the fire, the water cools rapidly. To retain heat in liquids, they should be confined in dense and polished vessels, as these are poor radiators. Hence, for boiling and cooking, rough and black vessels should be employed, but to keep the articles warm, dense and polished vessels should be used. It is for this reason that a silver teapot is better than an earthen one. But as silver is a good conductor of heat, the handle should be *insulated* by interposing between it and the vessel some non-conducting substance, as ivory or bone.

Stoves, being intended to radiate heat, should be rough and black, but fireplaces, being intended to reflect heat into the room, should be lined with white, dense, and polished substances, like glazed earthenware, or glazed fire-bricks.

304. Conduction is that property of bodies by virtue of which they transmit heat from molecule to molecule. When any body is heated by conduction, it must be of a lower tem-

perature than the parts of the body through which the heat comes to it.

Those bodies that transmit heat readily are called *good conductors;* those that do not transmit it readily are called *bad conductors.*

INGENHOUSZ showed that solid bodies possess different degrees of conductivity, by means of an apparatus shown in Fig. 206. It consists of an oblong vessel to contain water, from one side of which projects a system of short tubes for receiving rods of different kinds of solids, such as metals, marble, wood, glass, and the like.

He coated the different rods with a soft wax that would melt at about 140° F., and then filled the vessel with boiling water. Upon

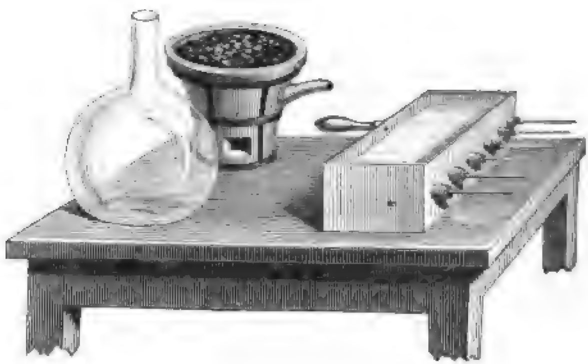


Fig. 206.

some of the rods the wax melted rapidly, upon some more slowly, and upon others not at all. This showed that the rods varied in their conductivity.

It has been shown that metals are the best conductors, after which comes marble, then porcelain, bricks, wood, glass, resin, etc.

Liquids are bad conductors of heat, except mercury, which is a metal. They are such bad conductors that RUMFORD asserted that water is not a conductor at all. More careful experiments have shown that all liquids are conductors, but extremely bad ones.

Gases are bad conductors of heat, but on account of the extreme mobility of their particles, it is difficult to establish the fact by direct observation.

305. Convection is the motion of the particles of the hot body carrying the heat with them. When a liquid is heated at the bottom it illustrates convection. The heated particles expand, and as they are then lighter than the cooler ones above them, they rise to the top of the vessel to give place to the heavier and cooler particles that supply their places. In this way a double current of particles is set up, as shown in the figure by the arrows, the hot ones rising and the cool ones descending. This process of circulation goes on till a uniform temperature is imparted to all of the liquid.

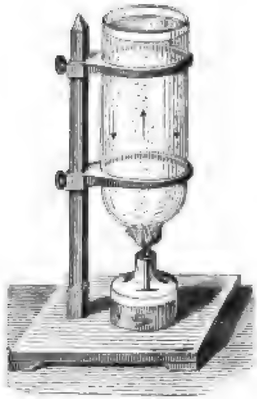


Fig. 207.

The circulation of particles may be shown by putting into the vessel (Fig. 207) particles of a substance of nearly the same density as the liquid; as, for example, oak sawdust. These particles will partake of the motion of the fluid, rising up in the centre, and descending along the walls of the vessel as shown in the figure.

Gases are heated by convection, in the same manner as liquids.

306. Applications of the Preceding Principles. — If the hand be placed upon different articles in a cold room, they convey different sensations. Metals, stones, bricks, and the like, feel cold, whilst carpets, curtains, and the like, feel warm. The reason of this is, that the former are good conductors, and readily abstract the animal heat from the hand, whilst the latter are bad conductors, and do not convey away the heat of the hand.

Wooden handles are sometimes fitted to metallic vessels which are to contain heated liquids. This is because wood is a bad conductor, and therefore does not convey the heat to the hand. For a similar reason, when we would handle any heated body, we often interpose a thick holder of woollen cloth, the latter being a bad conductor.

To preserve ice in summer, we surround it with some bad conductor, as straw, sawdust, or a layer of confined air. The same

means are adopted to preserve plants from the action of frost. In this case the non-conducting substance prevents the radiation of heat.

Cellars are protected from frost in winter by a double wall enclosing a layer of air, which is a non-conductor. It is the layer of confined air that renders double windows so efficient in excluding frost from our houses.

The feathers of birds and the fur of animals are not only in themselves bad conductors, but they enclose a greater or less quantity of air, which renders them eminently adapted to the exclusion of cold.

The bark of trees is a bad conductor, and so serves to protect them from the injurious effects of heat in summer and cold in winter.

Our warmest articles of clothing are composed of non-conducting substances, enclosing a greater or less quantity of air. Such are furs, woollen cloths, and the like. It is not that these are warm of themselves, but they serve as non-conductors, preventing the escape of animal heat from our bodies.

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- Radiant Heat. — Ray of Heat.
- Laws of Radiant Heat.
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SECTION V. — CHANGE OF STATE OF BODIES BY FUSION AND CONGELATION.

307. Fusion. — It has been stated that heat not only causes bodies to expand, but that it may in certain circumstances cause them to change from the solid to the liquid state, or from the liquid to the gaseous state.

When a body passes from a solid to a liquid state, it is said to *melt*, or *fuse*, and the act of changing state in this case is called *fusion*.

If a melted body is suffered to cool, it generally becomes solid at the same temperature at which it melted. Hence the melting-point is usually the same as the freezing-point.

The freezing-point may be lowered in various ways. That of water has been lowered several degrees below 32° F. A slight jar, however, will cause the water to freeze, and the temperature will instantly rise to 32°.

Fusion takes place when the force of cohesion, which holds the particles of a body together, is exactly balanced by the heat which tends to separate them. The temperature at which fusion takes

place is different for different bodies. For some bodies it is very low and for others very high, as is shown in the following table: —

Body.	Temperature of Fusion.	Body.	Temperature of Fusion.
Mercury . .	— 37.9° F.	Bismuth . .	512° F.
Ice	32°	Lead	620°
Tallow . . .	91°	Antimony . .	810°
White wax .	149°	Zinc	680°
Sulphur . .	239°	Silver . . .	1832°
Tin	451°	Gold	2282°

All bodies are not melted by the action of heat. Some are decomposed, such as paper, wood, bone, marble, etc. Simple bodies — that is, bodies which are composed of but one kind of matter — always melt if sufficiently heated, with a single exception. Even carbon, the most refractory of all known bodies, has been brought to a state of incipient fusion.

The passage from the solid to the liquid state is generally abrupt, but not always. Some bodies show no definite melting-point; for example, glass and iron gradually become softer and softer until the liquid condition is reached.

308. Latent Heat of Fusion. — Bodies which can be melted always present the remarkable phenomenon that when they are heated to the temperature of fusion, they cannot be heated any higher until the fusion is complete. For example, if ice be exposed to heat, it begins to melt at 32° F., and if more heat be applied, the melting is accelerated, but the temperature of the mixture of ice and water remains at 32° until all the ice is melted.

The heat that is applied during the process of fusion enters into the body without raising its temperature, and is said to become *latent*. When the body returns to its solid state, all the latent heat is again given out, and once more becomes ***sensible***.

Those who first used the term *latent heat* noticed that the thermometer did not respond to the heat that was communicated during the process of melting, and supposed that it was hidden away in the molecular spaces in a state of inaction; hence the name *latent*.

According to the present theory, the heat is expended in conferring potential energy upon the molecules, and performing the interior work of moving them into new positions. When the heat is withdrawn this potential energy becomes kinetic, and the molecules rush back again to their former condition with the same force used in separating them. The heat that was consumed now reappears, as has been said, in its original form of sensible heat.

The expression *latent heat*, although not in strict accordance with modern ideas, is nevertheless generally used by physicists as a matter of convenience.

There can be no confusion in its use if we understand it to mean simply *the amount of heat that must be communicated to a body in a given state in order to convert it into another state without changing its temperature.*

If we consider sensible heat to be *kinetic molecular energy* (Art. 263), then latent heat may be regarded as *potential molecular energy.*

The phenomenon of latent heat may be illustrated by the following experiment. If a pound of pulverized ice at 32° F. be mixed with a pound of water at 174° F., the heat of the water will be just sufficient to melt the ice, and there will result two pounds of water at the temperature of 32° F. During the process of melting, 142° of heat have been absorbed and become latent; hence we say that the heat required to melt ice at 32° F. is 142°; or, in other words, the latent heat of water at 32° is 142°.

The enormous amount of heat which becomes latent when ice melts explains why it is that large masses of ice remain unmelted for a considerable time after the temperature of the air is raised above 32° F. Conversely, the immense quantity of heat evolved when water passes to the state of ice explains why it is that ice forms so slowly in extremely cold weather. The absorption of heat in melting and the production of heat in freezing tend to equalize the temperature of climates in the neighborhood of large masses of water, like lakes and rivers.

309. Congelation. — Solidification. — Regelation. — Any body that can be melted by the application of heat can

be brought back to a solid state by the abstraction of heat. This passage from a liquid to a solid state is called *congelation*, or *solidification*.

In every body the temperature at which congelation commences is generally the same as that at which fusion begins. Thus, if water be cooled, it will begin to congeal at 32° F.; and, conversely, if ice be heated, it will begin to melt at 32° F. Furthermore, the amount of heat given out, or rendered sensible, in congealing is exactly equal to that absorbed, or rendered latent, in melting.

That this is really the case may be proved by the following experiment. If we take two vessels, the first containing one pound of water at 174° F., and the second one pound at 32° F., and expose them to the air during a cold winter day, so that equal amounts of heat shall escape from both during a given time, we shall find that the temperature of the water in the first vessel will immediately fall, while that in the second will remain stationary.

In the mean time the water in the second vessel will begin to freeze, but as long as the water keeps its liquid state the temperature will stay at 32°. When the last particle of water has frozen, and before the temperature falls, if we observe the temperature in the first vessel, we shall find it to be 32°. We see, therefore, that 142° of heat have been given out in the first vessel.

The same amount must also have escaped from the water in the second, but the temperature is not changed, because it is the heat of fusion given up by the water in changing into ice.

Some liquids cannot be congealed by the greatest cold to which we can subject them; such are alcohol and ether. Pure water congeals at 32°; the salt water of the ocean congeals at 27°; olive-oil at 21°; linseed and nut oils at 17°.

Water reaches its maximum density at 39.2°, and as its temperature is diminished from this limit, its volume continues to increase until congelation is completed.

When it passes from a liquid to a solid state the expansion is sudden and irresistible. The immense power of this expansion is seen in the bursting of water-pipes during a frost, the breaking of pitchers, tumblers, vases, etc., in which water has been left, when the temperature falls to 32°.

The following experiment illustrates this expansive force in a still more striking manner : —

An officer of the Artillery in Quebec filled a 12-inch shell (Fig. 208) with water, and closed the fusee hole with a wooden plug driven in with a mallet. It was then exposed to intense frost. When the water froze the plug was projected to a distance of several hundred feet, and a long cylinder of ice issued from the hole.

In another experiment the bomb split open and a sheet of ice was forced through the crack.

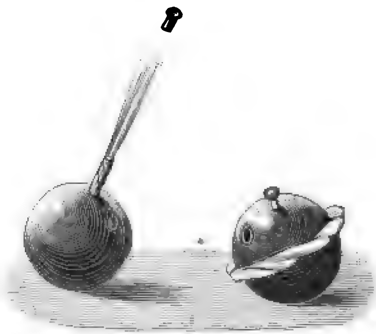

Fig. 208.

If two smooth pieces of melting ice be pressed against each other, they are soon frozen together. This phenomenon is called *regelation.*

Regelation is explained by supposing the interior of the ice colder than the outer layer just passing into the state of water. When the pieces are pressed together the layer of water at 32° F. has a colder body on each side. The latent heat of fusion of this layer is soon absorbed and conducted away, and the water is converted into ice. The formation of a snow-ball depends on regelation. Below a temperature of 32° F. the particles of snow are dry and regelation cannot take place. Hence a coherent snow-ball can only be made of melting snow.

310. **Crystallization.**—When bodies pass slowly from the liquid to the solid state, their particles, instead of arranging themselves in a confused manner, tend to group themselves into regular forms. These forms are called *crystals*, and the process of forming them is called *crystallization.*

Flakes of snow, sugar candy, alum, common salt, and the like offer examples of crystallized bodies. The forms of the crystals are best seen under a magnifying-glass.

Bodies may be crystallized in two different ways. In the first

case, we melt them, and then allow them to cool slowly. If a vessel of sulphur be melted and allowed to cool slowly, it will commence crystallizing about the surface, and if we break the crust thus formed, and pour out the interior liquid sulphur, we may obtain beautiful crystals of sulphur.

In the second case, we dissolve the body to be crystallized, and then allow the solution to evaporate slowly. The dissolved body is then deposited at the bottom and on the sides of the vessel in the form of crystals. The slower the process, the finer will be the crystals. It is in this manner that we crystallize candy and various salts.

311. Freezing Mixtures. — The absorption of heat which takes place when a body passes from a solid to a liquid state is often utilized in the production of intense cold. This result is best obtained by mixing certain substances, and these mixtures are then called *freezing mixtures.*

A mixture of one part of common salt and two parts of pounded ice forms a mixture that is used for freezing cream. The salt and ice have an affinity for each other, but they cannot unite until they pass to the liquid state. In order to pass to this state they absorb a great quantity of heat from the neighboring bodies, and this causes the latter to freeze. By means of a mixture of salt and snow the thermometer may be reduced to 0.

Summary. —

Fusion.
- Definition.
- Table of Fusion for different Substances.

Latent Heat of Fusion.
- Explanation of the Term *Latent.*
- Origin of its Use.
- What Latent Heat really accomplishes.
  - Examples.

Congelation.
- Definition.
- Heat given out in Freezing.
  - Experiment.
- Expansive Power of Water in Freezing.

Congelation (continued).
Experiment.
Regelation.
Explanation of the Term.
Crystallization.
Definition.
Methods of Crystallization.
Freezing Mixtures.

SECTION VI. — VAPORIZATION. — ELASTIC FORCE OF VAPORS.

312. Vaporization. — Volatile and Fixed Liquids. — When sufficient heat is applied to a liquid, it is converted into a gaseous form and is called a *vapor*. The change of state from a liquid to a gaseous state is designated by the general term *vaporization*.

If vaporization takes place slowly and from the surface, at ordinary temperatures, it is called *evaporation*; but if vapor is produced rapidly in the mass of the liquid itself, the process is termed *boiling*.

Some solids are capable of passing directly to a state of vapor without first becoming liquid. Iodine, arsenic, and camphor are examples of this class. This is called *sublimation*. Even the vapor of ice can be detected far below the freezing-point.

The number of vapors that exist at ordinary temperatures is very small. Of these, watery vapor is the most familiar, as well as the most important, on account of the part which it plays in many natural phenomena.

Liquids are divided into two classes, with respect to the readiness with which they pass from the liquid to the vaporous state, viz. *volatile liquids* and *fixed liquids*.

Volatile liquids are those which have a natural tendency to pass into a state of vapor even at ordinary temperatures, such as ether, alcohol, and the like. If a vessel of water, alcohol, ether, or chloroform be left exposed to the air, the liquid is slowly converted into vapor and disappears; in other words, it evaporates. To the class

of volatile liquids belong essences, essential oils, volatile oils, amongst which may be mentioned spirits of turpentine, oil of lavender, attar of roses, oil of orange, and the like.

Fixed liquids are those which do not pass into vapor at any temperature, as, for example, fish oils, olive oils, and the like. At high temperatures they are decomposed, giving rise to various kinds of gases, but to no true vapors that can be condensed into the original form of the liquid. Some oils, like linseed oil, harden on exposure to the air; but it is not by evaporation, but by absorbing oxygen from the air, and thus passing to a solid state.

313. Elastic Force of Vapors. — Vapors are generally colorless, and are endowed with an *expansive force*, or *tension*, which, when heated, may become very great.

This property may be illustrated by means of an apparatus shown in Fig. 209. It consists of a curved tube, the short branch of which is closed and filled with mercury; the mercury also fills a portion of the long branch. A small quantity of ether is introduced into the short branch, when it at once rises to the top, *B*, of this branch. At ordinary temperatures, the pressure of the external atmosphere exerted through the mercury is sufficient to prevent the ether from forming vapor.

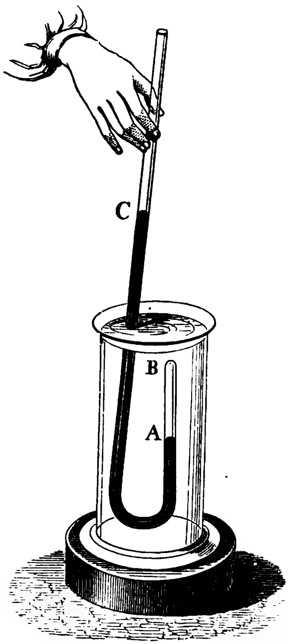

Fig. 209.

If, however, the tube is plunged into a vessel of water heated to 112°, the ether will be converted into vapor, and will occupy a certain portion, *A B*, of the tube, holding in equilibrium the pressure of the atmosphere, together with the weight of the mercurial column, whose height is *A C*.

If the tube is withdrawn and allowed to cool, the vapor of ether will be condensed, and will appear

as a liquid at *B*. If more heat be applied, it will again be converted into vapor, and the mercury will rise in the branch, *C*, as long as any ether remains to be evaporated. This shows that the tension of the vapor augments with the temperature. This principle holds true for all kinds of vapor.

The tension acquired by the vapor of water, or *steam*, often becomes so great by being heated as to burst the strongest vessels, and thus is the cause of frightful accidents. The cause of wood snapping when burned in a fireplace is the expansion of the water in the pores, giving rise at last to an explosion. When a chestnut is roasted in the ashes, the moisture within the shell expands into steam, and explodes with sufficient force to throw the nut from the fire. Hence it is that a small puncture is usually made in the shell, which permits the escape of the steam and prevents explosion.

314. Instantaneous Evaporation in a Vacuum. — Vapors formed upon the surface of a liquid escape by virtue of their tension. Under ordinary circumstances, the pressure of the air prevents a very rapid escape of vapor at ordinary temperatures, but when the atmospheric pressure is diminished in any way, evaporation takes place with great rapidity. If the pressure is entirely removed, the evaporation is instantaneous, like the flash of gunpowder, especially if the liquid is very volatile.

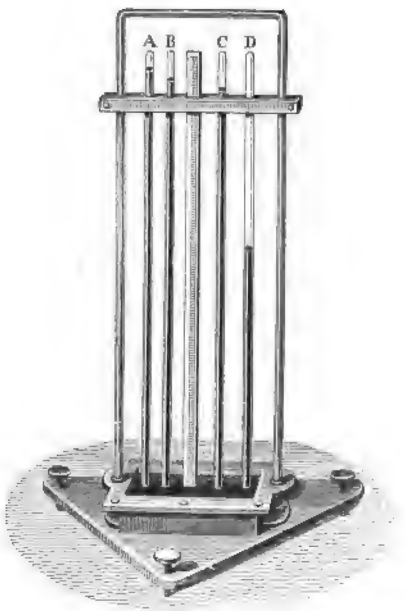

Fig. 210.

This principle may be

illustrated by means of the apparatus shown in Fig. 210. It consists of several barometer tubes, *A*, *B*, *C*, *D*, filled with mercury, and inverted in a common cistern of mercury, as shown in the figure. The whole apparatus is supported by a frame, to which is attached a graduated scale. The mercury will stand at the same height in all of the tubes, — at the height in *A*, for example.

If a few drops of water be introduced into the tube, *B*, they will rise through the mercury in the tube, and on reaching the vacuum will be instantly converted into vapor, as is shown by the depression that takes place in the column of mercury. If a little alcohol be introduced into the tube, *C*, it will, in like manner, be converted into vapor, and will produce a still greater depression of the column. If a small quantity of ether be introduced into the tube, *D*, a still greater depression of the mercury will be observed.

This experiment shows that the tension of the vapor of ether is greater than that of alcohol, and that of alcohol greater than that of water. By careful measurement, it is found that the tension of the vapor of ether is twenty-five times as great as that of water, and six times as great as that of alcohol.

315. Limit of the Tension of Vapors. — If a sufficient quantity of each of the liquids in the last experiment be introduced into the tubes, vapor will finally cease to form, and a portion will remain in the liquid state. In this case the tension of the vapor already formed is sufficient to balance the tendency of the liquid to pass into a state of vapor. In this state of affairs no more vapor can form without a change of temperature. This is the case supposed in the last article.

316. Causes that accelerate Evaporation. — The slow evaporation of water on the surface of our globe is accelerated by many causes, some of which are indicated below : —

1. *Temperature.* — Increase of temperature also increases the tension of the vapor formed, and accelerates evaporation.

This property is utilized in the arts in the manufacture of extracts.

The evaporation is carried on in chambers kept at temperatures of from 80° to 140° F., the air being continually renewed to carry off the vapor as fast as formed.

2. *Pressure.* — Diminution of pressure facilitates evaporation.

This principle has been utilized in the arts for the concentration of syrups. This application is illustrated by the method of concentrating syrups in sugar refining. The syrups are placed in large spherical boilers, from which the air is extracted by means of air-pumps worked by steam.

3. *Change of Air.* — A continual change of the air in contact with the liquid facilitates evaporation, by carrying off the vapor which would otherwise saturate the layer in contact with the liquid, and effectually check the formation of additional vapor.

It is for this reason that the surface moisture of our fields and roads disappears more rapidly when there is a breeze than in calm weather. In the arts, the principle is applied by keeping a current of air playing across the surface of the liquid to be evaporated, by means of blowers or otherwise.

4. *Extent of the Liquid.* — A large surface is favorable to rapid evaporation, by affording a great number of points from which vapor may be formed.

This principle is utilized in the arts by employing shallow and broad evaporating pans. This application is illustrated by the process of making salt from sea-water. The water is spread out in large pans, which are very shallow, and then exposed to the influence of the sun's rays, when the water slowly evaporates, leaving the salt in the form of crystals.

317. **Ebullition.** — Ebullition, or Boiling, is a rapid evaporation, in which the vapor escapes in the form of bubbles. The bubbles are formed in the interior of the liquid, and, rising to the surface, they collapse, permitting the vapor to pass into the air.

In heating water, the first bubbles are due to the small quantitie of air contained in the liquid, which expand and rise to the sur-

face. Afterwards, as the heat is kept up, particles of water are converted into vapor and rise through the liquid, becoming condensed by the colder layers of water above them. The formation and condensing of these first bubbles cause the *singing* noticed in liquids before they begin to boil. When all of the layers become suitably heated, the bubbles are no longer condensed, but rise to the surface, and escape with a commotion that we call boiling, as shown in Fig. 211.

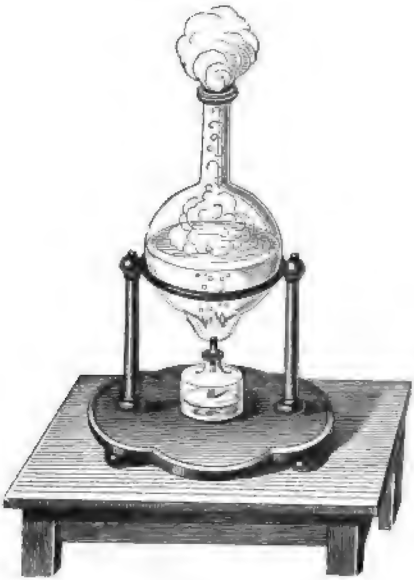

Fig. 211.

The following are the laws that govern the phenomena of ebullition: —

1. *Under the same pressure each liquid enters into ebullition at a fixed temperature.*

The temperature at which a liquid boils is called its *boiling-point.* When the barometer stands at 30 inches, the boiling-point of pure water is 212° F.; the boiling-point of ether is 108 F.; the boiling-point of alcohol is 174° F., and the boiling-point of mercury is 660° F.

2. *The pressure remaining the same, a liquid cannot be heated higher than the boiling-point.*

For example, if water be heated to 212°, it will begin to boil, and no matter how much heat may be applied, it will continue to boil, but will never become hotter than 212°; all the applied heat passes into the vapor and becomes latent. It becomes latent, because it does not heat either the water or the steam above 212°.

318. Causes that modify the Boiling-Point of Liquids. — The principal causes that influence the boiling-point of liquids are: *the presence of foreign bodies, variations of pressure*, and *the nature of the vessels* in which the boiling is effected.

Fig. 212.

1. *Presence of Foreign Bodies.* — Matter in solution generally raises the boiling-point of a liquid. Thus, a solution of salt does not boil so readily as pure water. If, however, the body dissolved is more volatile than water, then the boiling-point is lowered. Fatty matters combined with water raise its boiling-point. Hence it is that boiling soup is hotter than boiling water.

2. *Variations of Pressure.* — Increase of pressure raises,

and diminution of pressure depresses, the boiling-point. When the pressure is great, the vapor, in order to escape, must have a high tension, and this requires a high temperature. When the pressure is small, the reverse is the case.

This principle may be illustrated by the apparatus shown in Fig. 212. It consists of a bell-glass, connected with an air-pump. Beneath the glass is a vessel of water. If the air be exhausted from the bell-glass, the water enters into ebullition, even at ordinary temperatures. This is because the pressure is diminished.

If it is desirable to continue the ebullition for some time, an arrangement must be made to remove the vapor as fast as formed. This can be effected by placing a dish of sulphuric acid under the bell-glass. The acid absorbs the vapor with great avidity. Furthermore, there is no increase of temperature in the water, but, on the contrary, the temperature continually falls, and the water may even be frozen.

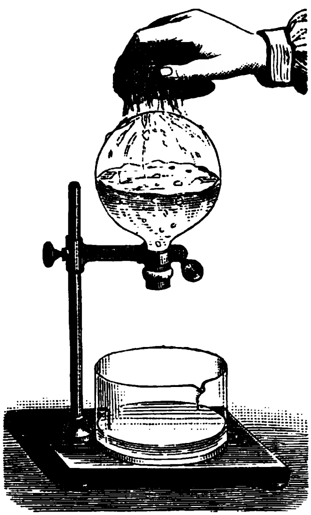

Fig. 213.

The influence of pressure on the boiling-point can also be illustrated by the following experiment. Take a flask (Fig. 213), about half full of water, expel the air by boiling, and when the steam is escaping cork it tightly and invert; the steam, by its pressure, will stop the boiling; pour cold water over it, the steam will be condensed, and, the pressure being removed, the boiling will begin again, which in its turn will cease if hot water be poured over it.

The height of a mountain can be approximately ascertained by observing the difference between the boiling-point at its summit and at its base. The higher we ascend the mountain, the less the pressure and the lower the boiling-point.

3. *Nature of the Vessel.* — When the interior of the vessel is rough, the projecting points form centres for developing vapor, and the boiling-point is lower than when the surface is smooth. Water boils at a lower temperature in an iron than in a glass vessel. In fixing the boiling-point of thermometers, a metallic vessel should always be employed to boil the water in, on account of the fact just mentioned.

319. Papin's Digester. — When water is heated in open vessels, its temperature cannot be raised beyond a certain limit, but in closed vessels both the water and its vapor may be raised to very high temperatures, so that the tension of the vapor may reach several atmospheres. The instrument employed to show this fact is called PAPIN'S *Digester*, so called because PAPIN invented it for extracting the nutriment from bones. The high temperature dissolves the gelatine.

It is represented in Fig. 214, and consists of a thick bronze vessel, *M*, whose cover is held in place by a screw passing through a strong frame. It is about two thirds filled with water and heated on a furnace.

The vapor accumulates, increases the pressure, and raises the boiling-point. To avoid danger of explosion, the instrument is provided with a safety-valve, similar to that used in steam-engine boilers. The safety-valve consists of a valve, *u*, fitting closely over an opening in the cover. This valve is held in place by a lever, *ab*, and a movable weight, *p*. One end of the lever is fastened at *a* by a hinge-joint. By moving the weight, *p*, along the lever, we may vary the force with which the valve, *u*, is kept in place.

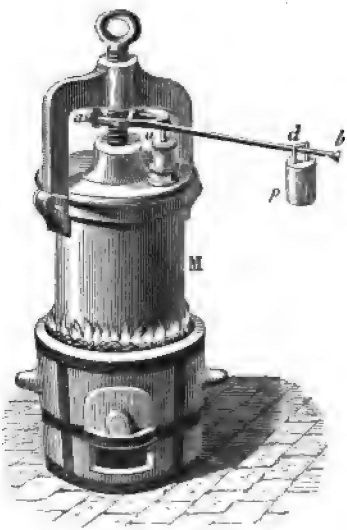

Fig. 214.

Whenever the tension of the vapor within the digester exceeds the

weight exerted upon the valve by the lever, the valve will be forced open, and a portion of the steam will escape with a whistling sound that indicates great compression. If the valve be left open, the temperature can only be raised to 212°, and we have the phenomena of simple boiling.

If water be heated in a well-corked bottle, the tension of the vapor will finally cause the cork to spring from its place with a loud explosion. It is the high tension of confined vapors that gives rise to the explosion of steam-boilers. Hence the necessity of constructing them of strong materials, and of providing them with proper safety-valves.

320. Measure of the Elastic Force of Vapor. — DALTON measured the elastic force of watery vapor at every temperature, from 32° F. up to 212° F.

His method, however, is wanting in precision, but REGNAULT, with a more complicated apparatus, obtained results of greater accuracy.

Two methods have been devised for determining the tension of aqueous vapor above 212°, one by DULONG and ARAGO, in 1830, and the other by REGNAULT, in 1844.

All the results that were reached prove that the tension increases very rapidly with the temperature.

321. Latent Heat of Vapors. — When a liquid begins to boil, all the heat that is added enters into the vapor and becomes latent. The amount of heat that becomes latent is different for different liquids. It is called the *latent heat of vaporization.*

What was said about the term *latent* in the case of *fusion* may be repeated concerning *vaporization*, namely, it is a convenient word to use.

It was also stated that this heat was really expended in conferring potential energy upon the molecules, and performing the interior work of moving the atoms into new positions. A greater amount of potential energy is conferred upon the molecules in the case of vapors; and more work is to be done, for besides the interior work of pulling apart the liquid molecules, there is the ex-

ternal work of pushing back the atmosphere so that the vapor can expand.

When the heat is withdrawn, the molecules rush back again to their former condition, with a kinetic energy equal to that employed in separating them. The heat that was consumed now reappears.

322. Latent Heat of Steam. — When the source of heat is the same, it takes about $5\frac{1}{2}$ times as long to change water into steam as to raise the same quantity of water from the freezing to the boiling point, 180°. We find the latent heat of steam to be $180 \times 5\frac{1}{2}$, or 990°; that is, it takes $5\frac{1}{2}$ times as much heat to convert any quantity of water into steam as to raise the same quantity from 32° to 212°.

This may be verified by mixing 1 lb. of steam at 212° with $5\frac{1}{2}$ lbs. of water at 32°. The result is $6\frac{1}{2}$ lbs. of water at 212°. The experiment can be performed by putting the 1 lb. of water into a flask, and connecting the flask by a tube with a beaker containing the $5\frac{1}{2}$ lbs. Then place the flask over the spirit-lamp or gas-jet, so that the steam shall pass through the tube into the water. The latent heat of the steam is given out, when it is condensed, and raises the temperature of the water to the boiling-point.

323. Examples of Cold produced by Heat becoming Latent. — If a few drops of ether be poured upon the hand and allowed to evaporate, a sensation of cold will be felt. The ether in evaporating extracts the heat from the hand, which becomes latent.

Damp linen feels cold when applied to the body, because the moisture in passing to a state of vapor extracts the animal heat, which, entering the vapor, becomes latent.

The warm wind of summer is refreshing, because it causes a more rapid evaporation of the perspiration, which abstracts animal heat from the body to become latent in the vapor thus produced. The coolness that results from sprinkling the floor of an apartment in summer arises from the passage of heat from a sensible to a latent state, in consequence of the evaporation of the water. For the like reason, a shower of rain is generally followed by a diminished temperature.

Water may be cooled by putting it in porous vessels. A small

quantity escapes through the pores, and in evaporating abstracts a portion of heat from the remaining liquid, thus reducing its temperature. This is the process of cooling water employed in many tropical countries.

324. **Spheroidal State.** — If a metallic disk be heated red-hot, and a little water be dropped upon it, the liquid does not wet the disk, but takes the form of a flattened globule, and rotates rapidly about on the bottom.

As the disk cools, it reaches a point where the spheroidal state cannot be maintained, and the water moistens the metal and goes off instantly in a cloud of steam.

This peculiar action of the water can be explained as follows: When it comes near the hot disk, steam is generated beneath it, which acts as a sort of cushion to keep it from the metallic surface.

That the globule of liquid is not in contact with the vessel was clearly proved by BOUTIGNY. He heated a silver plate and placed it in a horizontal position; then dropped upon it a little dark-colored water. When the water assumed the spheroidal condition, the flame of a candle placed at a little distance could be distinctly seen between the drop and the plate.

325. **Congelation of Water and Mercury.** — When evaporation is rapidly increased, the absorption of heat is proportionally increased, and as it is taken from the surrounding objects, these are sometimes frozen. It has been stated that water may be frozen under the receiver of the air-pump by absorbing the vapor as rapidly as it is generated.

By operating with a liquid more volatile than water, a greater degree of cold is produced. By using sulphurous acid, which boils at 14° F., a sufficient degree of cold is produced to freeze mercury. This is effected by surrounding a thermometer bulb with cotton, saturated with sulphurous acid, and then placing it under a receiver and exhausting the air.

The rapid vaporization abstracts so much heat from the mercury that it freezes in a few minutes. If we break the bulb, the mercury ·und in a solid mass, like a leaden bullet. In this form mercury

can be drawn out into sheets, or stamped like a coin; but it soon absorbs heat from neighboring bodies, and again passes to a liquid state.

The temperature of a liquid in the spheroidal state, explained in Art. 324, is always below its boiling-point. This property has been applied by BOUTIGNY in freezing water in a red-hot crucible.

He heated a platinum disk to a bright redness, and placed a small quantity of liquid sulphurous acid in it. The acid assumed the spheroidal state, and water dropped upon it was instantly frozen.

By using liquid nitrogen protoxide, instead of sulphurous acid, mercury can be frozen.

The boiling-point of the protoxide is about —94° F.

Summary. —

Vaporization.

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Volatile and Fixed Liquids.

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Instantaneous Evaporation in a Vacuum.

Experiment.

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Causes that accelerate Evaporation.

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2. Pressure
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4. Extent of the Liquid.

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Mercury by Liquid Nitrogen Protoxide in the Spheroidal State.

SECTION VII. — CONDENSATION OF GASES AND VAPORS. — SPECIFIC HEAT. — SOURCES OF HEAT AND COLD.

326. Causes of Condensation. — The CONDENSATION of a vapor is its change from a vaporous to a liquid state. This change of state may arise from *chemical action*, *pressure*, or *diminution of temperature*.

1. *Chemical Action.* — The affinity of certain substances for the vapor of water is so strong that they absorb it from the air, even when the latter is not saturated; such, for example, are quick-lime, potash, sulphuric acid, and many others. When placed in a closed space, they in a short time abstract all the moisture that is in it.

2. *Pressure.* — If a closed cylinder be filled with vapor, and this be compressed by a piston, as soon as the space occupied

by the vapor is saturated it will begin to condense, and if the pressure be continued all the vapor will be reduced to the liquid state.

Until the space becomes saturated, the pressure must be continually increased on account of the augmented tension of the vapor; but after liquefaction begins no further augmentation of tension takes place, and the pressure required to complete the liquefaction remains uniform.

3. *Diminution of Temperature.*—When the temperature of any space is diminished, the amount of vapor required for saturation is diminished. After the point of saturation is reached, any further diminution of temperature causes a deposit of the vapor in a liquid form.

Steam is colorless, but when allowed to escape into the cold air, condensation takes place in the form of drops, which become visible. For the same reason, the moisture contained in the breath becomes visible in cold weather.

In winter the glass of our windows often becomes coated with drops like dew. This arises from the fact that the glass is colder than the air of the room, and thus acts continually to produce condensation of the vapor in the air. If the difference of temperature is sufficient, the particles of vapor are frozen as they are deposited, producing beautiful crystallizations. When the external air is warmer than that within, the deposit takes place on the outside of the glass. If a vessel of cold water be placed in a warm room, a deposition of moisture takes place on its exterior surface.

327. Heat developed by Condensation. — When a liquid passes to a state of vapor, a great quantity of heat is absorbed from neighboring bodies, and becomes latent. When the vapor returns to a liquid state, an equal amount of heat is given out and becomes capable of affecting our senses; in other words, it becomes *sensible.*

328. Heating by Steam. — Buildings are heated by means of steam conveyed from a boiler in the lower story, through iron pipes in the walls. This steam, by its heat and

by the heat given out on condensation, serves to warm the apartments through which it is made to pass. To this end, coils of pipes are placed in the rooms to be warmed.

329. Distillation. — DISTILLATION is the process of separating liquids from each other by means of heat.

The most volatile of the liquids is most easily evaporated, and its vapor is then condensed. The heat should be kept above the boiling-point of the liquid that we wish to obtain,

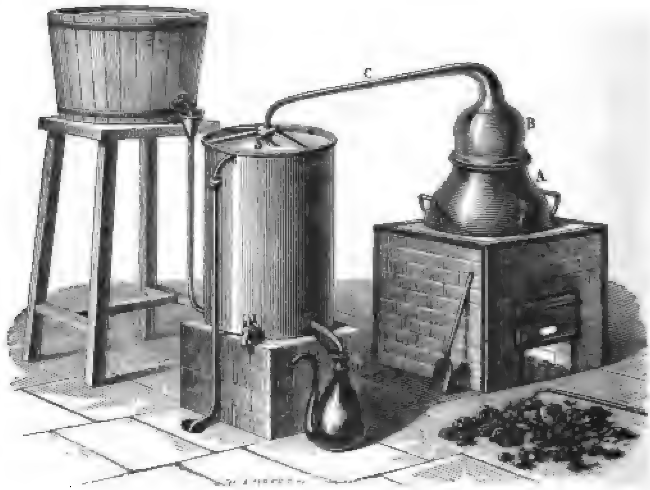

Fig. 215.

but below that which we wish to leave behind. The boiling-point of alcohol being 174° F., and that of water 212°, if a mixture of alcohol and water be heated up to some temperature between these limits, the alcohol will all be vaporized, whilst most of the water will remain behind.

330. Method of Distillation. — An ALEMBIC, or Still, is an apparatus for distillation.

The most usual form of an alembic is represented in Fig. 215. It is composed of a boiler, *A*, with a cover, *B*,

called the *dome*. From the top of the dome a metallic tube, *C*, passes into a vessel, *S*, called the condenser, and is then bent into a spiral form. This tube is called the *worm*, and after passing through the condenser, *S*, it leads to a *receiver*, *D*. The condenser, *S*, is kept full of cold water by an arrangement shown in the figure.

The substance to be distilled is placed in *A*, and a suitable heat is then applied. The more volatile portion is converted into vapor, rises into the dome, and, passing through the worm, is condensed, and escapes in a liquid form into the receiver, *D*.

Wine is composed of water, alcohol, and a coloring matter. If this liquid be placed in the alembic and heated to any temperature between 174° and 212°, the alcohol is separated from the other ingredients. As a portion of water is evaporated, the alcohol thus obtained is not pure, and will require to be distilled again. At each distillation the strength is increased, but no amount of distillation can render it absolutely pure.

By distillation, pure water may be obtained from the brine of the ocean, or from the impure water of our wells and springs.

331. Liquefaction of Gases. — All of the gases have been liquefied, either by pressure alone, or by a combination of pressure with a diminution of temperature. An immense pressure may be had by utilizing the tension of the gases themselves, by generating large quantities in confined spaces.

One of the most interesting examples of the liquefaction of a gas is that of carbonic acid, which is capable not only of liquefaction, but also of congelation. For this purpose two very strong cylinders are fitted together, both being hermetically sealed, and communicating by a pipe. One of these cylinders is the *generator*, and the other the *receiver*. In the generator are placed the ingredients necessary to generate carbonic acid, usually bicarbonate of soda and sulphuric acid.

After the opening is carefully closed, these materials are brought into contact, when an immense volume of carbonic acid is developed

and, being unable to expand, its tension becomes so great that a portion is condensed into a liquid form. The tension, at the temperature of 60° F., is equal to 50 atmospheres, or 750 lbs. on each square inch. As the use of this apparatus is attended with danger, it has come into general disfavor.

Another method is to draw the gas by a condensing-pump from a generator and to force it into a receiver.

After liquefaction has ceased, if a stopcock be turned so as to allow a part of the confined gas to escape, a portion of the liquid acid passes to a state of vapor with immense rapidity, and in doing so, absorbs so much heat from the remaining portion as to freeze it. The frozen acid is thrown out by the gaseous jet in flakes like snow. It is very white, and so cold as to freeze mercury instantly. It evaporates very slowly, and when tested with a spirit thermometer, its temperature is found to be 106° below the 0 of FAHRENHEIT'S thermometer.

If the solid acid be mixed with ether, it changes into a vapor rapidly, and intense cold is the result. If the mixture be placed under the receiver of an air-pump, the evaporation is more rapid, and greater cold is produced.

FARADAY obtained a temperature in this way of —166° F. A temperature of —220° F. was obtained by NATTERER by evaporating under the exhausted receiver a mixture of bisulphide of carbon and liquid nitrogen protoxide.

By powerful and ingenious appliances all the gases have been liquefied, but a detailed description of the apparatus cannot be given here.

332. Specific Heat of Solids and Liquids. — Experiment shows that different bodies require different amounts of heat to elevate their temperatures through the same number of degrees.

If equal weights of water, iron, and mercury have the same amount of heat communicated to them, the mercury will be most heated, the iron next, and the water least of all. When heated to a certain temperature, water absorbs ten times as much heat as iron, and thirty-three times as much as mercury.

Conversely, if the same quantities of these substances at 212° F. are allowed to cool down to the temperature of the atmosphere, the water will require a much longer time than either the iron or mercury, and will give out more heat.

In order to compare bodies with respect to the quantity of heat they absorb or give out, we take as a standard unit the amount of heat necessary to raise a given weight, say one pound, of water through 1° F. This is called a *unit* of *heat.*

333. Definition of Specific Heat. — *Specific Heat indicates the quantity of heat required to raise one pound of any substance 1° F., compared with the quantity necessary to raise the same weight of water 1°.*

Thus it requires $\frac{1}{30}$ as much heat to raise a pound of mercury 1° as it requires in the case of a pound of water, that is, $\frac{1}{30}$ of a unit of heat. Hence we say that the specific heat of mercury is $\frac{1}{30}$, or .033.

Two principal methods have been employed to ascertain the relative specific heat of bodies: (1) *The method of mixture;* (2) *By melting ice.*

334. The Method of Mixture. — In this method the body to be experimented upon is heated to a certain temperature, and then plunged into water at a lower temperature. The two bodies interchange heat and come to a common temperature. Then, from a knowledge of the weights of the two bodies mixed, their original temperatures, and their common resulting temperature, their relative specific heats may be determined.

If we mix one pound of mercury at 68° with one pound of water at 32°, the temperature of the mixture will be 33.15°. The water, therefore, has gained 1.15 units of heat.

This amount of heat, also, is evidently sufficient to raise the temperature of one pound of mercury from 33.15° to 68°, that is, through 34.85°.

Now, if 1.15 units of heat can raise the temperature of one pound of mercury 34.85°, it will take as many units to raise it 1° as 34.85°

is contained in 1.15, which gives as a result, .033 of one unit. This decimal expresses the specific heat of mercury. This method is simple and reasonably accurate, if proper care be used.

335. Method by Melting Ice. — In this method the bodies to be experimented upon are taken of equal weights, brought to a standard temperature, say 212° F., and then brought into contact with ice. The amount of ice melted makes known the quantity of heat given off by the bodies in passing from 212° to 32°, from which the relative specific heats may be determined.

An instrument called the *calorimeter* (Fig. 216) is used in this method. *M* contains the heated body, *A* the ice to be melted, *D* the outlet for the water of the melted ice. Ice is also placed at *B* to prevent the heat of the air from melting the ice at *A*. There is an outlet at *E* for the water which comes from the liquefaction of the ice in *B*. We can tell how much ice is melted by the different bodies by measuring the respective quantities of water that run off at *D*.

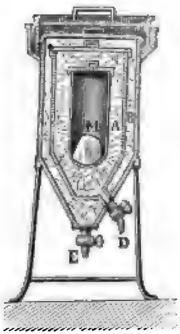

Fig. 216.

It will be found that equal weights of iron, sulphur, and mercury will melt, respectively, $\frac{1}{9}$, $\frac{1}{5}$, and $\frac{1}{30}$ as much ice as the same weight of water. Calling the specific heat of water *unity*, these fractions express the specific heat of the substances. Either of these methods may be used to find the specific heat of solids and liquids.

That the specific heats of different substances differ very widely from one another can be clearly seen from the following experiment. Take five balls of equal weights, made of iron, tin, copper, lead, and bismuth. Heat them to the same temperature, say 300° F.; then place them (Fig. 217) on a disk of wax. Every ball gives up some of its heat to the wax, causing it to melt.

The iron goes through the disk first, the copper next, then the tin, while the lead and bismuth are slower in their action, and will remain in the sheet of wax unless very thin.

336. Specific Heat of Gases is determined by passing a current of gas at a given temperature through a spiral glass tube placed in water. By noting the increase of temperature of the water, and knowing also the weight of the gas and the temperature to which it has been cooled, its specific heat can be calculated by a process similar to that given under the method of mixtures.

The same body has in the liquid state a greater specific heat than in the solid or gaseous. Thus, for instance, the specific heat of water is double that of ice and more than double that of steam.

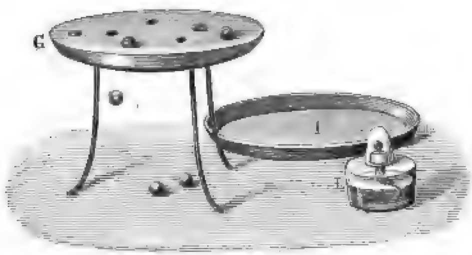

Fig. 217.

Hydrogen is the only known substance that has greater specific heat than water.

The following tables show the specific heat of a few of the most important substances, water being represented by unity.

The numbers express the average values for temperatures between 32° and 112° F.

TABLE FOR SOLIDS.

Substance.	Specific Heat.	Substance.	Specific Heat.
Glass	.177	Silver	.057
Iron	.114	Platinum	.032
Zinc	096	Tin	.056
Copper	.095	Lead	.031
Gold	.032	Antimony . . .	.050
Ice	.504	Sulphur	.202

TABLE FOR LIQUIDS.

Substance.	Specific Heat.	Substance.	Specific Heat.
Alcohol	.548	Ether	.515
Benzine	.395	Oil of Turpentine .	.462
Mercury	.033	Acetic Acid . . .	.658

TABLE FOR GASES

Substance.	Specific Heat.	Substance.	Specific Heat.
Hydrogen . . .	3.410	Steam	.480
Nitrogen	.243	Air	.237
Oxygen	.217	Chlorine	.121

337. **Sources of Heat.** — The principal sources of heat are: *the sun, electricity, combustion by chemical combination, pressure and percussion*, and *friction*.

1. *The Sun.* — The sun is the most abundant source of heat. We are ignorant of the cause of heat in the sun's rays.

It has been computed that the heat received from the sun by the earth in a year is sufficient to melt a layer of ice extending over the entire globe, and 100 feet in thickness. Yet on account of the great distance of the earth from the sun, and its comparatively small size, it can receive only the minutest portion of the heat which the sun radiates in all directions.

2. *Electricity.* — The subject of heat due to electricity will be treated of under the head of Electricity.

3. *Combustion by Chemical Combination.* — Chemical combinations are generally accompanied by a disengagement of heat. When they take place slowly, the heat is inappreciable; but when they take place rapidly, there is often produced an intense heat, and sometimes a development of light.

Combustion is one form of chemical combination. The forms of combustion exhibited in our fireplaces and our lamps is a combina-

tion of the carbon and hydrogen of the wood and oil with the oxygen of the air. The products of such forms of combustion are watery vapor, carbonic acid, with gases and volatile products that appear under the form of smoke. Combustion is a decomposition of certain substances, accompanied by a composition of new products. In this change no element is lost; simply a change of form takes place.

The flame produced in combustion is a mixture of gaseous and volatile matters, heated red-hot by the heat disengaged in the process of combustion.

The process of respiration is a species of slow combustion, in which the carbon and other matter of the blood unites with the oxygen of the air. This species of combustion gives rise to the heat of the body of men and animals. This heat is called *animal heat.*

Fermentation is a chemical process that gives rise to heat.

4. *Pressure and Percussion.* — Whenever a body is compressed so as to reduce its volume, heat is developed. The greater the compression, the greater the amount of heat developed. If gas be suddenly and violently compressed (Fig. 218), the heat generated is sufficient to set fire to inflammable bodies.

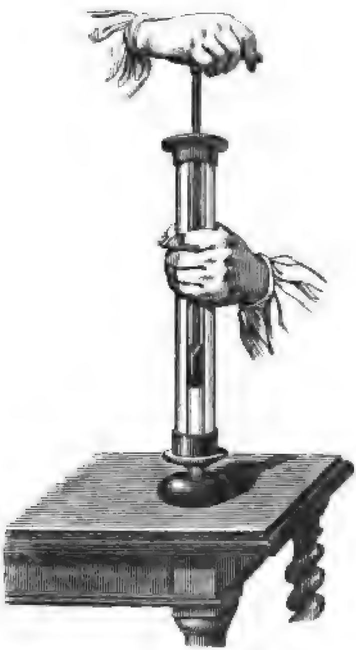

Fig. 218.

Percussion is a source of heat. If a body, like a piece of metal, for example, be hammered, it soon becomes hot. It is percussion that causes the heat when a flint is struck against a piece of steel. In this case there is a piece of the steel detached and rendered red-hot by the collision.

5. *Friction.* — Friction is the resistance which one

body offers to another when they are rubbed together. This resistance is accompanied with a great development of heat. In this way many savage tribes procure fire, by revolving the end of one piece of dry wood in the cavity of another. Pieces of ice, when rubbed together, generate heat enough to melt them. In machinery, the friction on axles often sets them on fire, especially when lubrication has been neglected.

The development of heat by friction can be strikingly shown with the apparatus devised by Tyndall.

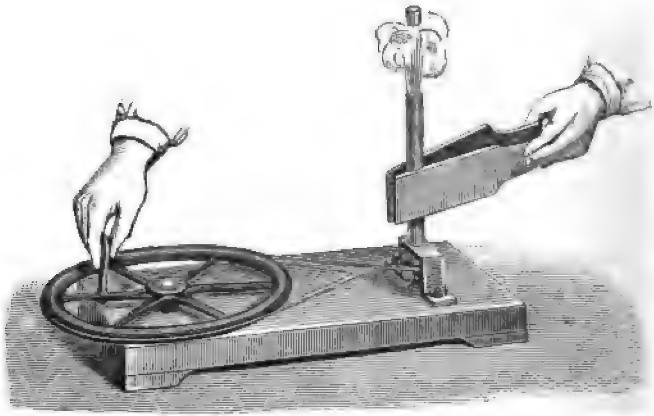

Fig. 219.

A brass tube, about 7 inches in length and $\frac{3}{4}$ of an inch in diameter, is nearly filled with water and corked. This is attached to a whirling table, as represented in Fig. 219. When the tube is rotated rapidly and pressed with a wooden clamp, the friction produced heats the water in a few minutes to the boiling-point, and the cork is driven out by the steam.

338. **Sources of Cold.** — The principal sources of cold are: *fusion*, *vaporization*, *expansion of gases*, and *radiation of heat*.

1. *Fusion.* — When a body melts, it absorbs heat from the surrounding bodies, which becomes latent in the melted body.

2. *Vaporization.* — When a liquid passes to a state of vapor, it absorbs heat, which becomes latent in the vapor. Both of these causes of cold have been considered already.

3. *Expansion of Gases.* — When a gas is compressed, it gives out heat; and, conversely, when it expands, it absorbs heat. This heat acts to keep the particles asunder, and the farther apart the particles are kept, the greater the amount of heat required.

Heat is the repulsive force that keeps a body in a gaseous state at all, or even in a liquid state.

If air be compressed in a condenser and then allowed to escape into the atmosphere, a slight cloud will be formed; this is due to the cold generated by the expanding air, which condenses the vapor in the air. This experiment illustrates the manner in which clouds are formed in the upper regions of the atmosphere.

4. *Radiation.* — Radiation produces cold in the radiating body, because radiation is simply giving off heat.

Summary. —

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Definition.
Causes of Condensation.
1. Chemical Action.
2. Pressure.
3. Diminution of Temperature.
Heat developed by Condensation.
Heating by Steam.
Distillation.
Definition and Illustration.
An Alembic, or Still.
Description.
Mode of Operation.
Liquefaction of Gases.
Method of liquefying Carbonic Acid Gas.
Method of producing Intense Artificial Cold.
Specific Heat of Solids and Liquids.
Explanations and Illustrations.
Unit of Heat.

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Illustration.
Methods of ascertaining the Specific Heat of Bodies.
1. Method of Mixture.
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Of Solids.
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Sources of Heat.
1. The Sun.
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Experiment illustrating Heat by Friction.
Sources of Cold.
1. Fusion.
2. Vaporization.
3. Expansion of Gases.
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SECTION VIII. — THERMO-DYNAMICS.

339. **Definition of Thermo-dynamics.** — The science which treats of the connection between heat and the mechanical work it can perform, and determines, by means of numbers, the relation between the quantity of heat supplied and the quantity of work done, is called *Thermo-dynamics.*

340. **Conservation of Energy.** — Energy, as previously defined, is the power of doing work, and consists of two

types, kinetic and potential. There can be no destruction or creation of energy, in any of its varied forms, by any means at our command.

As the quantity of matter in the universe is invariable, so is the quantity of energy. Neither can be annihilated. Heat, we have seen, is a form of energy. If put out of existence *as heat,* it re-appears in some other form of energy; but the energy itself, the power of doing some kind of work, of overcoming some kind of resistance, remains undiminished.

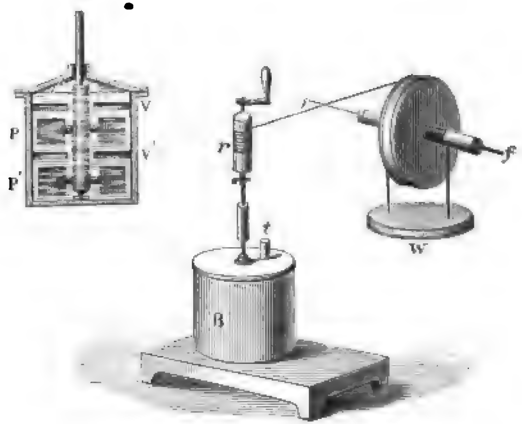

Fig. 220.

The principle of the conservation of energy when applied to heat is commonly called the First Law of Thermo-dynamics, which may be stated as follows: *When heat is transformed into work, or work into heat, the quantity of heat is equivalent to the quantity of work.*

341. Mechanical Equivalent of Heat. — The law given in the last article was established in a large measure by the following experiment of JOULE.

The apparatus used by him consisted of a brass paddle-wheel (Fig. 220), furnished with eight sets of revolving arms working between four sets of stationary vanes. The vanes, V V', are seen in the enlarged section at the left; also the paddles, P P'.

These parts of the apparatus are enclosed in a cylindrical copper or brass vessel, *B*, which is filled with water. The vanes prevent the water from being carried round bodily in the direction of rotation. The descent of the weight, *W*, causes the paddles to turn by means of the cord, *r*.

The friction of the paddles against the water raises its temperature, which is measured by the thermometer, *t*. It was found by JOULE with this machine that the quantity of heat which would raise one pound of water 1° F. is exactly what would be produced if a pound weight, after having fallen through a height of 772 feet, has its motion arrested by collision with the earth. The same effect would be produced by 772 pounds falling one foot.

Conversely, the amount of heat necessary to raise a pound of water 1° would, if it could be all utilized, be capable of raising a pound weight 772 feet high, or 772 pounds one foot high.

Now, the force necessary to raise one pound one foot is called a *foot-pound*. Then 772 foot-pounds are equivalent to one unit of heat. Physicists now call 772 foot-pounds the *mechanical equivalent of heat.*

By repeating the experiment with other liquids, and by using a smaller apparatus with an iron paddle-wheel revolving in mercury, JOULE obtained results similar to those where water was used.

342. Transformation of Energy. — The great characteristic of energy is its capability of being, as a general rule, readily transformed, and yet, in all its transformations, the quantity present remaining precisely the same.

We can explain this principle best by examples. The motion of the hammer when brought down upon a piece of metal is changed into heat; and could we gather up the heat produced by the shock of the hammer, and apply it without loss, it would lift it to the height from which it fell.

Pouring mercury from one cup to another raises its temperature. The water at the base of a cataract has a higher temperature than that at the top. The heat in these two instances is generated by the arrested motion of the mercury and water, and the friction of their molecules against the air. When a train of cars is stopped the motion is changed into heat. A bullet going through the air is warmed by friction. If the earth's motion should be suddenly arrested, immense heat would be developed.

We have an example of the conversion of heat into mechanical energy in the case of the steam-engine. The heat changes the water into steam, and this, by means of the expansive force it also receives from the heat moves a piston.

We have here a change of invisible molecular motion to visible motion of the mass.

The heat produced in the body by the various changes the food undergoes, in digestion and assimilation, is expended in muscular activities.

The heat energy of the sunbeam is stored up in coal in the form of potential energy.

We might multiply examples indefinitely if there were space for further illustration of the principle.

343. **Dissipation of Energy.** — We find it a comparatively easy matter to convert mechanical energy into heat, but we cannot get all the heat back again into work. During the process of converting heat into mechanical effect, there is always a transfer of a large quantity from a body of a higher to one of a lower temperature, without any work being done.

Take, for instance, the steam-engine. Some of the heat, it is true, is doing useful work in conferring expansive power upon the steam; but a large portion of it is lost, so far as conversion into mechanical energy is concerned, in heating the machinery and by radiation into the air.

It is claimed that mechanical energy is changing more and more into heat, and that all bodies will, by conduction and radiation of this heat, eventually acquire the same temperature.

And since we cannot get any work out of heat unless we have bodies of different temperatures — for heat passes from hotter to colder substances, — therefore, when the whole universe has reached the same temperature, all forms of life and motion will cease, and the earth will be no longer habitable by man. All the energy that exists will be in the form of diffused heat. This principle, called Dissipation, or Diffusion, of Energy, was first pointed out by Sir William Thomson.

344. The Steam-Engine. — A STEAM-ENGINE is a combination of pieces for utilizing the expansive force of steam and converting it into a motive power.

It consists essentially of two parts: first, the boiler, in which the steam is generated; secondly, the cylinder, where the expansive force of the steam is applied.

345. The Power of Steam. — Let *A B* (Fig. 221) represent a glass tube of uniform bore, and *C*, a piston, fitting it steam-tight, and suppose a little water to be in the tube below the piston. If heat be applied to the bottom of the tube by means of a spirit-lamp, the water will be converted into steam, and the piston will be driven to the top of the tube. If the lamp be removed, and the tube allowed to cool, the steam will be condensed, and the pressure of the atmosphere will drive the piston back to its original position. By again applying heat, and withdrawing it, the operation may be repeated, and so on indefinitely. This simple experiment involves the fundamental idea of the steam-engine.

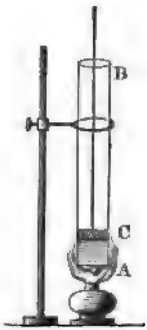

Fig. 221.

Under the ordinary pressure of the atmosphere, a cubic inch of water gives 1,700 cubic inches, or nearly a cubic foot, of steam. In this case the expansive force of the steam is in equilibrium with the pressure of the atmosphere, and it is said to have a *tension* of 15 pounds to the square inch. If a cubic inch of water be converted into steam, under a pressure of two atmospheres, it will yield but 850 cubic inches of steam, but the *tension* will now be 30 pounds to the inch.

In general, the volume of steam yielded by a given volume of water varies inversely as the pressure under which it is generated, and in all cases the *tension* of the steam is equal to this pressure. In round numbers, we may say that the conversion of a cubic inch of water into steam produces a quantity of work sufficient to raise a weight of one ton through a height of one foot.

346. Varieties of Steam-Engine. — Steam-engines may be either *condensing* or *non-condensing*. In the former, the steam, after having acted upon the piston, is condensed, and

the warm water returned to the boiler; in the latter, the steam is not condensed, but, after having acted upon the piston, is blown off into the air. In condensing engines steam may be, and often is, used of a lower tension than 15 pounds to the inch, in which case the engines are called *low-pressure engines*. In non-condensing engines steam is always used of a tension greater than 15 pounds to the inch, and the engines are then called *high-pressure engines*.

Condensing engines are more economical of fuel, but are heavier and more complex in their construction. Hence they are generally used as stationary engines. Non-condensing engines are used for locomotives, and where fuel is cheap are often employed as stationary engines.

The efficiency of a steam-engine is measured in terms of a unit called a *horse-power*, that is, a force which is capable of raising a weight of 33,000 pounds through a height of one foot in one minute. Thus, an engine that can perform a work equivalent to raising 33,000 pounds through 10 feet in one minute is said to be an engine of 10 horse-power.

347. Boilers and their Appendages.—The BOILER is a shell of metal, generally of wrought iron, but sometimes of copper, in which steam is generated.

Boilers are made of various shapes. One of the simplest has the form of a cylinder with rounded ends. Sometimes two smaller cylinders, also with rounded ends, called *heaters*, are placed below the main shell, and connected with it by suitable pipes. The object of this arrangement is to increase the heating surface. In the Cornish boiler the cylindrical shell has a large flue passing through it, containing an internal furnace. Sometimes two such flues exist. The tubular boiler has a great number of tubes, or flues, passing through it, for transmitting the flame and heated gases from the furnace.

The boiler and its appendages are variously arranged in different engines, the object in all cases being to obtain the greatest amount of steam with a given quantity of fuel. In stationary engines the furnace is usually made of brick or some other bad conductor of heat, and the flues are so arranged as to bring the flame and heated gases in contact

with as large a portion of the boiler as possible. In locomotive engines the fire-box is made of boiler-iron, and is so constructed that it is nearly surrounded by the water in the boiler.

Fig. 222 represents a side view, and Fig. 223 a cross-section of a cylindrical boiler with the heaters attached, such as are used for stationary engines.

These heaters, indicated in the figure by *B b*, are filled with water, and connected with the boiler by the tubes, *P P P*, while the boiler is only about half full.

The flame of the furnace, *c*, plays directly against the heaters; the heated gases and smoke are returned under the main cylinder in the flue, *O* (Fig. 223), and finally discharged into the chimney

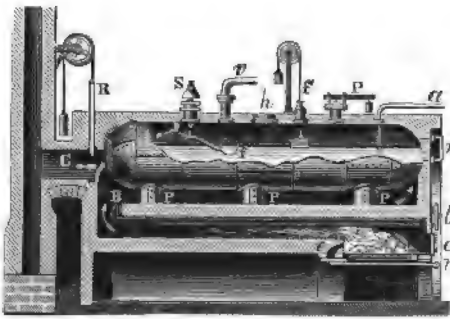

Fig. 222.

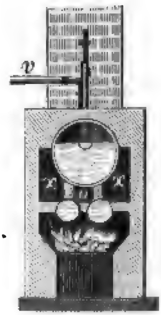

Fig. 223.

through the side flues, *x x*. The heat is thus utilized to a greater extent.

The principal appendages of the boiler are the following, as represented in Fig. 222.

Furnace, or fireplace, *c*.

The alarm-whistle, *s*, so arranged as to be opened by the float, *f*, when the level of the water falls too low.

Another kind of indicator of the level of the water in the boiler is represented at *f′*. It consists of a float connected with a counterpoise by a wire passing over a pulley, and through a packing-box in the top of the boiler. The position of the counterpoise tells the height of the water.

Still another indicator, which is sometimes used, is seen at *n*. It

consists of a thick glass tube, bent twice at right angles, the lower end being under the water and the upper end above. The water will stand at the same level in the tube as in the boiler.

P represents the safety-valve (see Art. 319).

v, the pipe that conducts the steam to the steam-chest.

a, the pipe for the admission of feed-water to the boiler; it reaches nearly to the bottom.

h, the man-hole, an aperture by which the boiler can be repaired and cleansed.

R, the damper to regulate the draught.

C, the flue leading to the chimney. The chimney is usually of great height, so as to secure a good draught.

348. The Manometer.—The MANOMETER, or pressure-gauge, for measuring the tension of steam in the boiler, is not shown in the figure.

These are not all based upon the same principle. Some are simply siphon barometers whose long branch is open, the short branch connecting directly with the boiler. The steam from the boiler forces the mercury up the long branch, and the higher the column the greater the pressure of steam.

This manometer, which is called the *open manometer*, answers well enough for low pressures; but for high ones the length of tube necessary renders it very inconvenient.

The closed manometer is shown in Fig. 224, and differs from the one just described in having its vertical tube closed at the top. It is graduated on the principle enunciated in MARIOTTE's law.

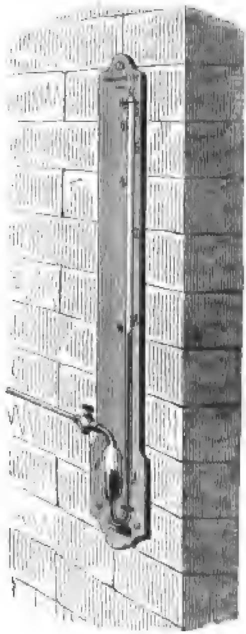

Fig. 224.

When the pressure in the boiler is one atmosphere, the mercury

in the cistern and tube are at the same level, the tension of the steam and the elastic force of the air just balancing each other. When the pressure becomes two, three, four, etc., atmospheres, the air in the closed tube will occupy one half, one third, one fourth, etc., the space it did before, allowance being made for the weight of the mercury which is forced up into the tube. The instrument having been graduated, its use is evident. When it is desired to ascertain the tension of the steam in the boiler, the cock is turned, and the height to which the mercury ascends in the tube indicates the tension in atmospheres. Any number of subdivisions may be made in either of the two manometers described.

The liability of glass tubes to break, and to lose their transparency by the mercury clinging to their sides, renders them somewhat objectionable. They are not adapted, either, to machines in motion.

The cheapness of metallic manometers has caused them to be used for a great number of boilers. We shall mention only the one constructed by BOURDON. The principle is this: If we allow the steam from the boiler to enter a flexible and elastic tube, that has been flattened a little and then coiled, the pressure will tend to uncoil it. Shut off the steam, and the tube, by virtue of its elasticity, resumes its original position.

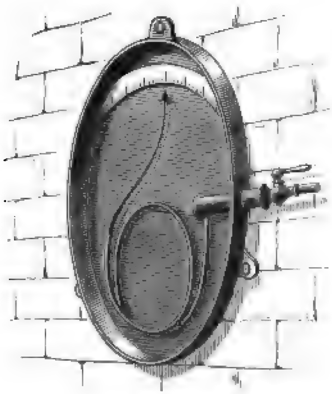

Fig. 225.

Fig. 225 represents such a manometer. One end of the tube is connected with a pipe leading to the boiler; to the other end is attached a steel needle, which traverses a scale. As the pressure of steam on the interior surface increases, it gradually uncoils, and the hand points to the number of atmospheres of pressure. When the pressure is removed the needle returns to its former position.

349. Mechanism of the Condensing Engine. — The essential parts of a condensing engine are shown in Fig. 226. The figure is only intended to illustrate the prin-

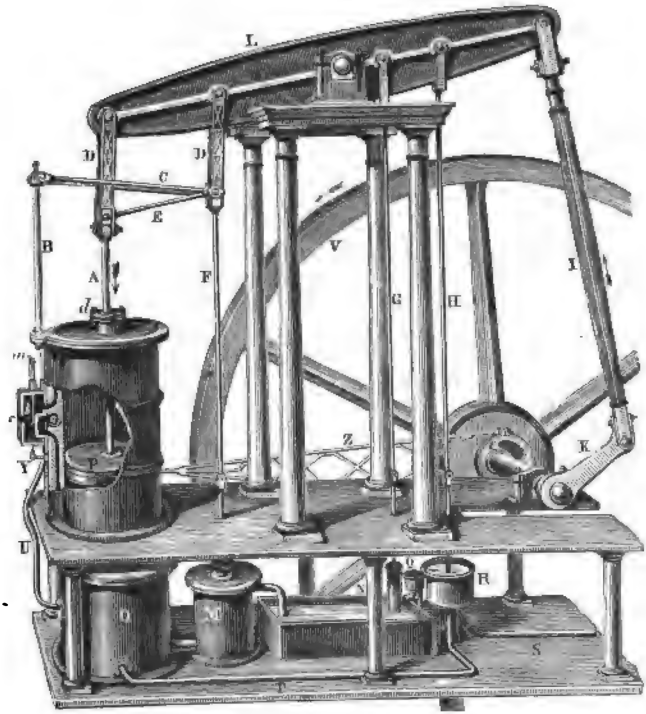

Fig. 226.

ciples of the engine, and, for the purpose of illustration, the parts are arranged in such a manner as will best exhibit them at a single view.

The principal parts of the condensing engine are the following: —

The *cylinder*, shown on the left, with a portion broken away.

The *piston, P*, which receives the action of the steam, alternately

on its upper and lower faces, and is thereby moved up and down in the cylinder.

The *steam-chest, b,* into which the steam from the boiler enters through the *steam-pipe* at *o,* and from which it passes through the *steam-passages,* alternately to the upper and lower ends of the cylinder.

The *sliding-valve,* moved up and down by the rod, *m,* which alternately opens a communication between the steam-chest and the two steam-passages leading to the top and bottom of the cylinder.

The *eduction-pipe, U,* connecting with the cylinder at *a,* by which the steam, after having acted upon the piston, is conducted into the *condenser, O.*

The *piston-rod, A,* working through a *packing-box, d,* which transmits the motion of the piston to the *working-beam, L.*

The *parallel bars, D D,* and the *radial bars, C E,* which keep the piston-rod from pressing against the side of the packing-box. This arrangement is called *Watt's parallel motion.*

The *connecting-rod, I,* which transmits the motion of the working-beam to the *crank-arm, K,* and through it imparts a motion of rotation to the shaft of the engine.

The *fly-wheel, V,* which obviates to a certain extent the irregularities of motion in the engine.

When the crank is at its highest or lowest position the steam has no power to move it. In either of these positions, called the *dead points,* the machine would come to rest if it were not for the fly-wheel, which, by its inertia, carries the piston and crank over these points, and brings them again under the power of the steam. The steamboat and locomotive need no fly-wheel, inasmuch as the inertia of the moving mass suffices.

The *eccentric, e,* which, acting like a crank, produces a backward and forward motion in the *connecting-rod, Z.* This rod, acting on the *bent lever, Y,* causes the rod, *m,* of the sliding-valve, to move up and down.

The *cold-water pump, R,* worked by the rod, *H,* which draws cold water from a reservoir, and forces it through the pipe, *T,* into the condenser. This pipe, terminating within the condenser in a *rose,* delivers the water in the form of a shower, and condenses the steam.

The *air-pump*, *M*, worked by the rod, *F*, which draws the hot water and the air that is mixed with it from the condenser, and forces it into the hot well, *N*.

The *feed-pump*, *Q*, worked by the rod, *G*, which draws the water from the hot well and forces it into the boiler.

To explain the action of the engine, let the position of the parts be as represented in the figure. The steam entering the steam-chest finds the upper passage open, and, flowing through it, acts upon the upper face of the piston and drives it to the bottom of the cylinder. The steam below the piston meanwhile flows through the lower passage, and, entering the eduction-pipe at *a*, is conveyed to the condenser, where it is condensed. When the piston reaches the bottom of the cylinder, the eccentric acts upon the bent lever to open the lower and close the upper passage. The steam from the steam-chest now flows through the lower passage, and, acting upon the lower face of the piston, forces it to the top of the cylinder. Meantime the steam above the piston, flowing down the upper passage, enters the eduction-pipe, and is conveyed to the condenser. When the piston reaches the top of the cylinder, the eccentric again acts to change the position of the sliding-valve, and thus the motion of the piston is continued indefinitely.

350. The Governor.—In many engines the supply of steam to the cylinder is regulated by an apparatus called the *governor*. One form of this contrivance is shown in Fig. 227.

A B is a vertical axis, connected with the machine near its working point, and revolving with a velocity proportional to that of the working point; *F E* and *G D* are arms turning with the axis, and bearing heavy balls, *D* and *E*, at their extremities; the arms are attached by hinge-joints at *G* and *F* to two bars, *C G* and *C F*, and these bars are connected by hinge-joints with the axis at *C*. The arms, *FE* and *GD*, are also connected by hinge-joints with a ring, *H*, which is free to slide up and down the axis, *A B*.

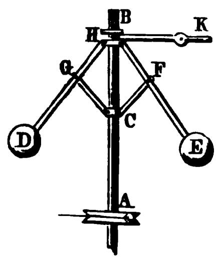

Fig. 227.

When the axis revolves, the centrifugal force developed in the balls causes them to recede from *A B*, and depresses the ring, *H*. This causes the lever,

B K, to turn about its fulcrum, *K*, and when the velocity has become sufficiently great, the lever operates to close a valve and shut off the motive power. When the velocity again diminishes, the balls approach the axis, the ring, *H*, rises, and the valve is opened. The governor may be adjusted so as to secure any desirable velocity at the working point.

351. Action of the Eccentric. — The automatic movement of the sliding-valve by means of the eccentric needs a more detailed explanation than is given in the preceding article.

The eccentric (Fig. 228) consists of a circular piece of metal, *c*, so attached to the shaft of the engine that its centre does not coincide with the axis of rotation.

The eccentric is surrounded with a ring of metal which does not rotate, but follows the motion of the eccentric, thereby receiving a

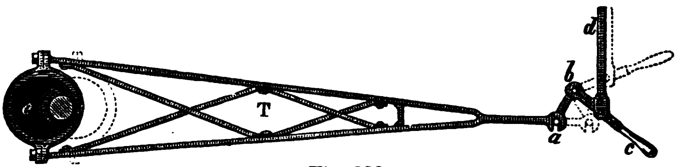

Fig. 228.

motion back and forth in a horizontal direction. This movement is transmitted by the arm, *T*, to the bent lever, *a b c*, causing it to turn about the point, *b*. This rotation of the lever raises and lowers alternately the rod, *d*, which is connected with the sliding-valve; thus an upward and downward motion is also imparted to this valve.

352. The Locomotive. — Fig. 229 represents a section of a locomotive, the principal parts of which are the following: —

The *boiler*, *B B*, with its *flues*, *p p*, and *safety-valve*, *M*. The dotted line represents the height of the water in the boiler.

The *fire-box*, *A*, communicating with the *smoke-box*, *C*, by means of the *flues*, *p p*. The fire-box has a double wall, the interval being filled with water and communicating with the boiler. *E* is the *grate*, and *D* the *door* for the supply of fuel.

The *steam-pipe*, *S S*, conveys the steam from the *steam-dome* to

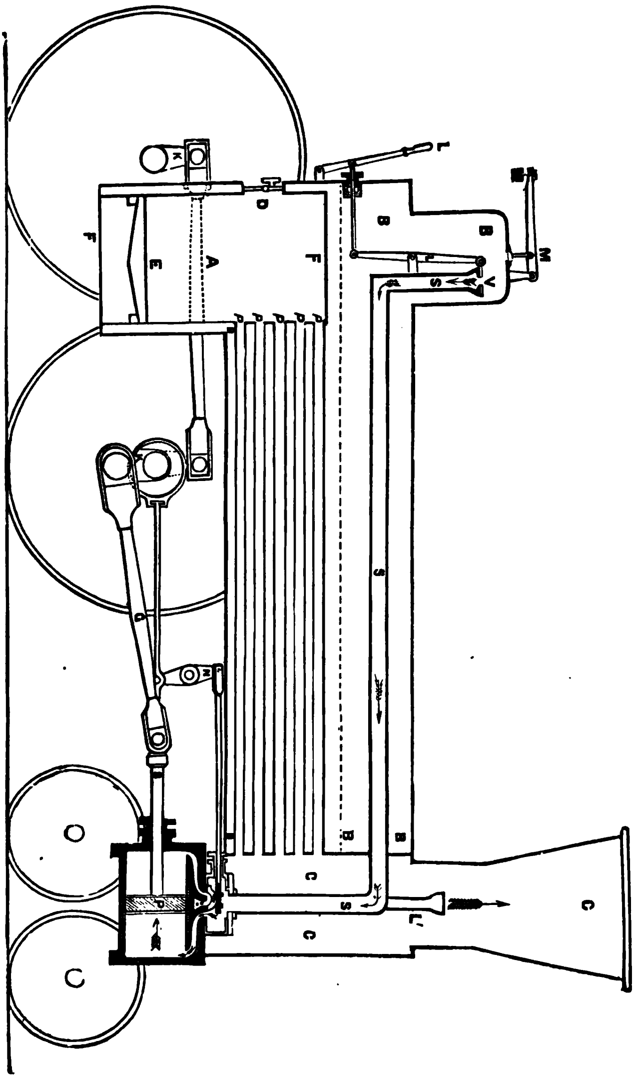

Fig. 229.

the *steam-chest.* It may be closed by a valve, *V*, worked by a lever, *L*.

The *steam-dome* is an elevated portion of the boiler, the object of which is to permit the steam to enter the steam-pipe without any admixture of water, as might be the case were the steam taken from a lower level.

The *cylinder*, the *piston*, *P*, and the *piston-rod*, *R*, are similar to the corresponding parts of the condensing engine.

The *blast-pipe*, *L'*, through which the steam is blown off after having acted upon the piston, terminates in the *smoke-box*, and the blast of steam from it serves to increase the draft of air through the flues, and thus promotes the combustion of fuel.

The *connecting-rod*, *G*, transmits the motion of the piston to the *crank-arm*, by means of which a rotary motion is imparted to the driving-wheels of the locomotive.

The manner in which steam acts to impart motion to the piston is the same as in the engine already described.

Summary. —

Thermo-dynamics.
- Definition.

Conservation of Energy.
- Explanation.
- First Law of Thermo-dynamics.

Mechanical Equivalent of Heat.
- Description of Joule's Apparatus.
- Mode of Operation.
- Results of this Experiment.

Transformation of Energy.
- Illustration by Examples.

Dissipation of Energy.
- Explanation.
- Illustration.
- Possible Results of Dissipation.

The Steam-Engine.
- Definition.

The Power of Steam.
- Illustration by Experiment.

Varieties of Steam-Engines.
- Condensing and Non-condensing.
- Definition.

Boilers and their Appendages.
- Boilers of various Shapes.
- Boiler, with Appendages, of Stationary Engine, illustrated by Figure.
- Open Manometer.
- Closed Manometer.
- Bourdon's Manometer.

Mechanism of the Condensing Engine.
- Illustrated by Figure.
- The Governor.
- Illustrated by Figure.

The Locomotive.
- Illustration of the Principal Parts by Figure.

SECTION IX. — HYGROMETRY. — RAIN. — DEW. — WINDS. — SIGNAL SERVICE.

353. **Hygrometry.** — HYGROMETRY is the process of measuring the amount of moisture in the air with respect to the amount necessary to saturate it.

When a given space has taken all of the vapor that it can contain, it is said to be *saturated*. For example, if water be poured into a bottle filled with dry air, and the bottle be hermetically sealed, a slow evaporation will go on until the tension of the vapor given off is equal to the tendency of the remaining water to pass into vapor, when it will cease. In this case the space within the bottle is saturated.

If the temperature varies, the amount of vapor required to saturate a given space will vary also. The higher the temperature, the greater will be the quantity of vapor required to saturate the given space; and the lower the temperature, the less the quantity required for saturation.

The quantity of watery vapor in the atmosphere varies with the *seasons*, *temperature*, *climate*, and different *local causes;* but notwithstanding the continued evaporation that is taking place from lakes, rivers, and oceans, the air in the lower regions of the atmos-

phere is never saturated. The reason is, that the vapor, being less dense than the air at the surface, rises into the higher regions, where it is condensed by the greater cold existing there, and falls to the earth in the form of rain.

The object of hygrometry is not to determine the absolute amount of moisture in the atmosphere, but simply to find out its degree of saturation, or, in other words, its *humidity*. When the air is completely saturated, its humidity is said to be 100; when half saturated, 50; and so on. The absolute amount of moisture remaining the same, the atmosphere might at one temperature be saturated, whilst at some other temperature it would be far from saturation.

In winter the air is generally damper than in summer, though in the latter season it generally contains a greater absolute amount of vapor than in the former. This is due to difference of temperature. For the same reason the air is damper at night than in the daytime and a cold room is damper than a warm one.

354. The Hygroscope. — A HYGROSCOPE is an instrument for showing the amount of moisture in the air.

Any substance capable of absorbing moisture may be employed as a hygroscope. A great number of animal and vegetable substances, such as paper, parchment, hair, catgut, are elongated by absorbing moisture, and are shortened when dried, and are therefore adapted to the construction of a hygroscope.

Instruments of this kind are very uncertain in their action, and are therefore used as matters of curiosity rather than for any scientific value they may possess.

355. The Hygrometer. — A HYGROMETER is an instrument for measuring the amount of moisture in the air.

Several kinds have been invented, the most important of which are, 1. hygrometers of absorption; 2. dew-point hygrometers; 3. wet and dry bulb hygrometers.

The hygrometers of the first class are really hygroscopes. The *hair hygrometer* is the most trustworthy of this class. It is based on the property which organic substances have of elongating when moist, and contracting when dry.

The hair is connected with a needle, and by its expansions and contractions causes it to move over an arc, thus indicating that the air is more or less moist. To this class belong those chimney ornaments that indicate moisture in the air. They are founded on the property which twisted strings or pieces of catgut possess of untwisting when moist and twisting when dry.

356. Daniell's Dew-Point Hygrometer. — The temperature at which vapor is deposited in the form of dew is called the *dew-point*. Daniell's hygrometer enables us to determine the amount of vapor in the atmosphere by indicating the dew-point.

It consists (Fig. 230) of two bulbs connected by a siphon-tube, from which the air has been expelled by hermetically sealing the bulb, *B*, when the instrument is filled with ether-vapor. The bulb, *A*, is about half filled with ether, and contains the bulb of a small thermometer. *A* is made of black glass, so that the deposition of dew may be more readily perceived.

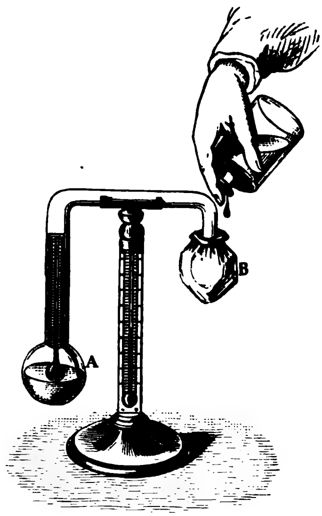

Fig. 230.

The bulb, *B*, is covered with muslin, and ether is dropped upon it. This evaporates from the muslin, cools the bulb, *B*, condenses the vapor of ether in it, and causes rapid evaporation from the surface of the liquid in the bulb, *A*. This is cooled until the air in contact with it sinks below the dew-point and moisture collects on the bulb. At the moment of deposition the height of the mercury in *A* is noted. The addition of ether to the bulb, *B*, is then discontinued, the temperature of *A* rises, and the dew disappears. When this takes place, read the thermometer in *A* again.

The two observations should not differ much from each other, and their mean is the dew-point. The thermometer in the centre of the stand gives the temperature of the air.

The nearer the dew-point is to the temperature of the air, the nearer the air is to being saturated with vapor.

357. The Wet and Dry Bulb Hygrometer. — This instrument consists of two similar thermometers, placed on a stand a short distance from each other, as shown in Fig. 231. The bulb of one is covered with muslin, and is kept moist by means of a wick dipping in water. The bulb of the other is kept dry, and indicates the temperature of the air.

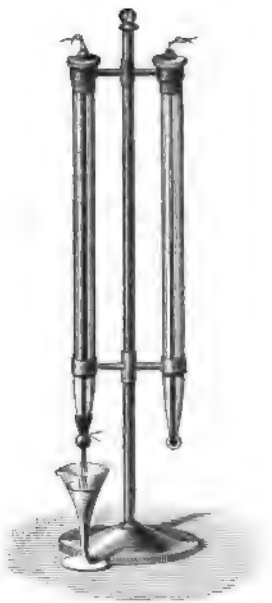

Fig. 231.

The evaporation that takes place from the wet bulb lowers its temperature below that of the other thermometer.

The greater the difference between the readings of the two thermometers, the dryer is the air, or the further from complete saturation.

The evaporation will go on unless the air is fully saturated.

This hygrometer, on account of the facilities of observation it affords, is more generally used than any other.

358. Mists, Fogs, and Clouds. — Mists, Fogs, and Clouds are masses of vapor condensed into drops or vesicles by coming in contact with colder strata of the atmosphere. The term *fog* or *mist* applies when these masses are in contact with the earth, and the term *cloud* when they are suspended in the air. A fog differs from a mist more in degree than in kind. We generally call a very thick mist a fog.

The air at all times contains a greater or less quantity

of invisible vapor, and if at any time the air becomes cooled below a certain limit, a portion is condensed and becomes visible; the result is either a fog or a cloud.

One of the most common causes of clouds is the cold generated by an ascending current of air. When the air becomes heated it expands and ascends, and, being continually subjected to a diminishing pressure, it expands rapidly, and a large amount of heat must become latent. This absorption of heat produces cold enough to condense the vapor into clouds. When a cloud floats into a warmer stratum of the atmosphere, it is often converted into invisible vapor and disappears. It is *dissolved.*

Mountains arrest the winds blowing from the plains, and force them to ascend their sloping sides. Coming in contact with the colder strata of the atmosphere, the moisture is converted into clouds and fogs. Hence we often see the mountain-tops covered with fogs and clouds when the other portions of the sky are clear. The condensation of water on the sides of mountains is the most fruitful source of our streams. When a cold wind meets with a warm and moist current of air, the cooling process is so great as to generate clouds.

Two theories have been advanced to explain the reason why clouds remain suspended in the air. According to the *first* theory, the particles of moisture are hollow spheres of water, like soap-bubbles, filled with air less dense than that without. Consequently the little vesicles float in the air like so many minute balloons. According to the *second* and favorite theory, the particles are extremely small, and float in the air in the same way that particles of dust and other small bodies are seen to be borne along by the atmosphere.

Fogs and mists form over bodies of water and moist grounds, when the air above them is cooler than the water or earth.

They are frequent along the course of rivers and upon inland lakes. The cause of the dense fogs that prevail in the neighborhood of Newfoundland is the Gulf Stream. The water brought by the Gulf Stream is warmer than that of the surrounding ocean, and as the vapor rises from it, it is converted by the cold air from the neighboring regions into fog.

359. Varieties of Clouds. — Clouds have been divided, according to Howard, into four principal kinds: *nimbus*, *stratus*, *cumulus*, and *cirrus*. These four kinds are represented in Fig. 232, and are designated, respectively, by one, two, three, and four birds on the wing.

Howard calls any cloud *nimbus* from which rain is descending, although it is not strictly one of the fundamental varieties, but a combination of several.

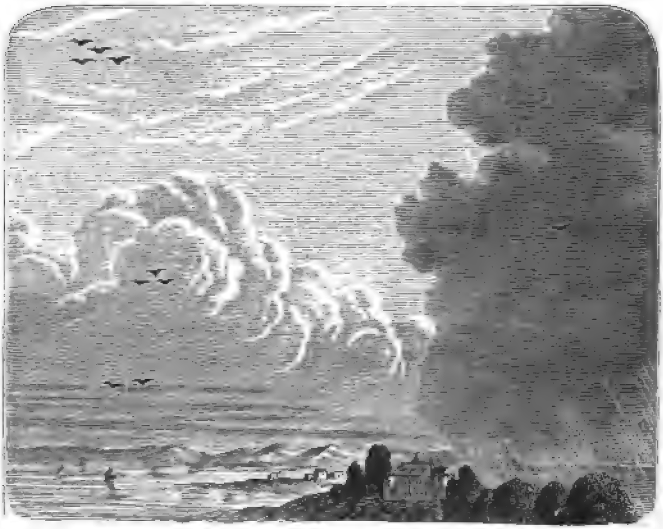

Fig. 232.

The *stratus* clouds consist of horizontal sheets. They occupy a low position in the atmosphere. They are frequently formed at sunset and disappear at sunrise.

The *cumulus* clouds are rounded masses that look like mountains piled one on the other. They are summer clouds.

The *cirrus* clouds are light, feathery clouds, and occupy the highest regions of the atmosphere. They are probably composed of frozen particles.

It must not be supposed that these four fundamental forms are

always distinctly outlined in the atmosphere. They frequently pass into one another and form intermediate types.

360. Rain. — RAIN is a fall of drops of water from the atmosphere. When several particles of a cloud unite, the weight becomes too great to be supported by the air, and the drop thus formed falls to the ground.

When a cloud floats into a colder stratum of the atmosphere, it becomes more condensed, and we have a fall of rain. When it floats into a warmer stratum, it dissolves. Hence we often see the clouds of the morning dissolve under the influence of the sun, which acts to heat the upper regions of the atmosphere.

The quantity of rain that falls in any country depends upon its neighborhood to the ocean or other bodies of water, upon the season, upon the temperature, and upon the prevailing direction of the winds. More rain falls near the coasts than in the interior; more rain falls in summer than in winter; more rain falls in tropical climates than in temperate and polar climates; and, finally, more rain falls in those countries where the prevailing winds are from the ocean than where they are from the continents.

The following table indicates the number of inches of rain that fall during the year at the places named: —

At Copenhagen	18	inches.
" Paris	22	"
" Havana	90	"
" Calcutta	81	"
" Grenada	126	"

From this we see that the quantity of rain increases rapidly as we approach the equatorial regions.

361. Dew and Frost. — DEW is a deposition of watery particles that takes place upon the soil and plants during the calm nights of summer.

The true theory of dew was first established by WELLS. According to his theory, dew results from the earth and plants becoming cooled by radiation, thus producing a de-

posit of moisture from the neighboring strata of air. Good radiators are soonest covered with dew, whilst bad radiators have little or no dew formed upon them.

The state of the atmosphere influences the amount of dew. When the air is clear the dew is abundant; when cloudy, little or no dew is formed. In this case the clouds reflect back the radiated heat, and thus prevents the earth from cooling so rapidly. A strong breeze prevents the formation of dew by removing the strata of air next the earth before they have time to be cooled down to the point of saturation, or the *dew-point*. A gentle breeze may facilitate the formation of dew by replacing the layer of air from which the water has been deposited by another which contains more moisture.

The freezing of water artificially in the tropical climate of India, depends upon this same principle of the radiation of heat from the earth during the night. Shallow pits are dug and in them some straw is laid, and upon the straw are placed broad, flat pans of water. The water loses its heat by radiation, and not being able to receive an equivalent supply from the earth on account of the poor conducting power of the straw, its temperature sinks below the freezing point and ice is formed. (The drops of water and the coating of frost seen on the glass of our windows in winter, are explained in Art. 326.)

The nearer the air is to saturation, the more abundant is the deposit of dew. Hence, before a rain, the deposit is specially abundant. Stone walls and the like, being cooler than the atmosphere, are often in summer covered with moisture, when they are said to sweat. The moisture in this case is condensed from the air.

WHITE FROST is nothing more than frozen dew. It is often seen in autumn, and arises under the same circumstances as are favorable to the formation of dew. In order that frost may occur, the earth must be cooled below 32° F.

It is often said that it freezes harder when the moon shines than when it is concealed by clouds. This is the case, but the moon has nothing to do with the freezing. The true explanation of the phenomenon is this: When the moon shines, it is generally cloudless, and the radiation goes on more rapidly, and of course a greater degree of cold is produced. On the contrary, when the moon is obscured, it is generally cloudy; and the clouds as stated above reflect back the heat, and the heat they send back to the earth is nearly or quite

enough to compensate for that radiated from the earth; hence the process of freezing is either retarded or entirely prevented.

Plants are good radiators, hence they are more likely to be affected by frost than other objects. To protect them from frost we cover them with mats, which prevent radiation, or rather reflect back the heat that the plants throw off.

362. Snow and Hail. — SNOW is formed by the freezing of vapor in the upper regions of the atmosphere, whence it falls to the ground in flakes.

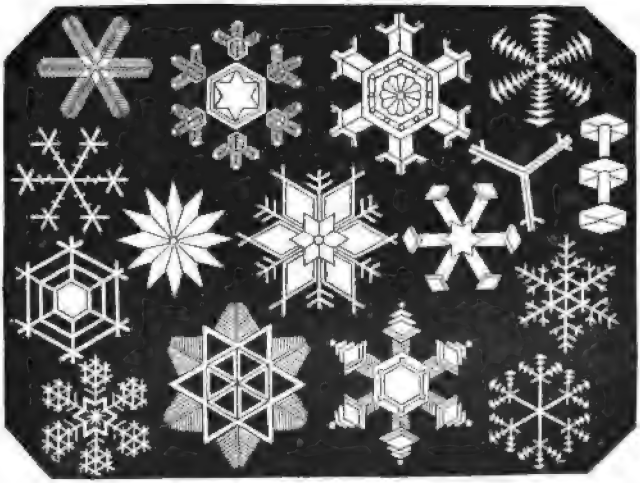

Fig. 233.

Snow-flakes are made up of crystals, arranged in star-like forms, with three or six branches, differently arranged, but always remarkable for their regularity and beauty. When snow falls, the temperature of the air is near 32° F. If the temperature is much lower, the snow is less abundant, because the amount of vapor in the air is less.

Fig. 233 shows some of the forms as seen through a miscroscope.

The quantity of snow that falls in any place is generally the greater as the place is nearer the pole, or as it is higher above the level of the ocean. At the poles, and on the summits of high moun-

tains in all latitudes, snow remains through the entire year. As we approach the equator, the region of perpetual snow rises higher and higher above the level of the ocean. In the Andes, under the equator, the limit of perpetual snow is between 15,000 and 16,000 feet above the level of the ocean; in the Alps it is only 10,500 feet above the level of the ocean; toward the northern extremity of Norway it is but 3,000 feet above the ocean level.

HAIL is composed of layers of compact ice, arranged concentrically about nuclei of snow. The formation of hailstones has never been satisfactorily explained, especially the great size of some of them.

Hail is supposed by some to be due to the freezing of rain-drops in their passage through strata of air colder than those in which they were formed.

Others suppose a cold current of air forces its way into a mass of air much warmer than itself and nearly saturated, the temperature being reduced below 32° F.

363. Winds. — WINDS are currents of air, moving with greater or less rapidity. They are generally named from the quarter whence they blow; thus, a wind that blows from the east is called an east-wind, and so for other winds. Winds are sometimes named from some local peculiarity. Thus, we have *trade-winds*, *monsoons*, *siroccos*, and the like. The prevailing directions of the wind are different in different countries, for reasons that will be explained hereafter.

364. Causes of Winds. — Winds are caused by variations of temperature in the atmosphere; these variations produce expansions and contractions, thus disturbing the equilibrium of the atmosphere, causing currents. These currents are winds. For example, if the air is more heated over one country than over the neighboring countries, it dilates and rises, its place being supplied by the colder air which flows in from the surrounding regions. The surplus of air thus brought in flows over at the top of the ascending column. Hence there is a current near the earth in one direction, whilst

at a higher elevation there is a current flowing in a contrary direction.

365. Regular, Periodic, and Variable Winds. — Winds are divided into three classes: REGULAR WINDS, PERIODIC WINDS, and VARIABLE WINDS.

1. *Regular Winds.* — Regular winds are those which blow throughout the year in the same direction. They occur in the neighborhood of the equator, extending on each side about 30 degrees. From their advantage to commerce they are called *trade-winds.* On the north side of the equator they blow from the northeast; on the south side they blow from the southeast.

The trade-winds arise from currents of air flowing from the polar regions towards the equator; the velocity of the earth about its axis being greater as we approach the equator, these winds lag behind, as it were, and become inclined to the westward, giving northeast winds on the north side, and southeast ones on the south side of the equator.

2. *Periodic Winds.* — Periodic winds are those which, at regular intervals of time, blow from opposite directions. Such are the *monsoons* that prevail in the Indian Ocean, blowing one half of the year from northeast to southwest, and the other half in the opposite direction. When the sun is on the north of the equator, the southern portion of the Asiatic continent is warmer than the southern part of Africa, and the winds blow from southwest to northeast; when the sun is on the south side of the equator, the reverse is the case.

The *simoom* is a hot wind that blows from the deserts of Africa. It is felt in the northern and northeastern parts of the African continent. During its prevalence the thermometer often rises to 120° F. In the desert this wind becomes suffocating from its heat and dryness. Travellers exposed to it cover their faces with thick cloths, and their camels turn their backs to escape its injurious effects.

The *sirocco* is a hot wind that sometimes is felt in Italy. When it blows people remain in their houses, taking care to close every door and window. Some suppose this to be a continuation of the simoom from the African desert.

The *land and sea breezes* are winds that blow on the sea-coast. During the day the land becomes heated to a higher degree than the sea; consequently the air resting on the land becomes more heated and rarefied than that on the water; hence it ascends, and the cooler air from the sea flows in towards the land to take its place, constituting the *sea-breeze.*

During the night the land cools more rapidly than the sea, and a contrary effect is produced. The air over the sea becomes warmer, and rises to make way for the cooler and denser air coming from the land. This current is called the *land-breeze.*

3. *Variable Winds.* — Variable winds are those which blow sometimes in one direction and sometimes in another, without any apparent law of change. The further we recede from the equatorial regions, the more variable are the winds in their character.

This is undoubtedly due to the fact that the two great currents of air that form the trade-winds gradually approach each other in temperature, at a distance from the equator, and lose that regularity of action that marks their movements in the tropical regions.

The current coming from the poles grows warmer, and that going towards the poles grows cooler, so that in the temperate zones the disparity of temperature is not sufficiently great to keep the currents distinct, and therefore there is a constant tendency to mingle and interchange their positions.

366. Tornadoes. — A Tornado is a violent whirlwind, attended with rain, thunder, and lightning. They are supposed to be caused by currents of air encountering one another when moving in different directions, thereby imparting to the atmosphere a whirling motion. Tornadoes often travel considerable distances, overturning buildings and uprooting

trees; they are accompanied with a noise like that of heavily loaded carts driven over a stony road.

Two species of tornado are recognized, *terrestrial* and *marine*, according as they take place on land or on water. The latter class present remarkable phenomena. The rotary force of the wind raises the water in the form of a cone, while a second cone forms in the cloud, having its apex downwards. These cones move to meet each other, forming a column of water reaching from the ocean to the cloud. In this form the column of fluid is called a *water-spout*. When a water-spout strikes a ship it does immense damage.

367. **Velocity of Winds.**—The velocity of winds is exceedingly variable. The velocity is measured by instruments called *anemometers*. These consist of a species of windmill attached to a train of wheel-work, by means of which the number of revolutions per minute can be registered. From the number of revolutions the velocity can be computed.

Fig. 234 represents this form of anemometer. It consists of four hemispherical cups attached to horizontal arms of equal length. These turn freely about a vertical axis.

Fig. 234.

This axis carries an endless screw, which sets in motion a train of wheel-work. The number of revolutions is registered on a dial by means of pointers connected with the wheel-work.

The velocity of the gentlest breeze, or zephyr, is not more than one mile per hour; a moderate wind travels at the rate of $4\frac{1}{2}$ to 5 miles per hour, a brisk wind 20 miles per hour, a tempest 40 to 50 miles per hour, and a hurricane from 90 to 100 miles per hour.

368. The Signal Service. — Attempts to predict important changes in the weather, so as to give timely warning of the approach of storms and tempests, have been made by civilized communities from time immemorial. These attempts, however, have of necessity been, to a great extent, crude and ineffectual. The coming storm could not be foretold in sufficient season to admit of making preparations for averting its violence.

By means of the electric telegraph the Signal Service of the present day has reached a high state of efficiency, and is of great value to commerce and agriculture. By its aid intelligence of storms and approaching weather-changes can be transmitted from point to point many hours in advance.

That the Signal Service is a part of the regular army inspires confidence in its work and gives trustworthiness to its reports. The thorough discipline of the army is essential to the successful working of the corps of weather-observers. There must be, on the part of its members, punctuality, prompt obedience, and the closest attention to the minutest details. There must also be the power to enforce these requirements, and this can be perfectly secured in the army.

Every man of the signal corps is thoroughly instructed and practised in the use of the telegraph and other instruments that are employed in every branch of the service.

The total number of stations of observations within the limits of the United States is between two and three hundred. Each station is equipped with the following instruments: barometer, thermometer, hygrometer, anemoscope, anemometer, and rain-gauge. All the stations communicate with the central office at Washington.

Three observations are taken daily, Washington time; this insures the reading of the instruments by all the observers at the same time. The instruments are read in the order given above.

The reports from the different stations are transmitted in cipher to the central office and entered on weather-maps. From the study of these maps the probable weather changes for the next twenty-four hours are deduced. Everything must be entered on the maps and acted on in a few minutes. The weather deductions are then fur-

nished to the press for publication, also telegraphed in bulletin form to different centres for the use of farmers, besides being given to the Associated Press for distribution throughout the country.

Not only is the state of the weather in the various great districts of the country given and a brief synopsis of the probabilities, but also an insight into the manner by which the probabilities are determined and the reasons for the predictions.

When severe storms are approaching the lakes or the sea-coast, cautionary signals are ordered at the central office to be displayed at the lakes and seaports and along the sea-coast as a warning to mariners.

For fuller details of this important and interesting topic the student is referred to the annual reports of the Chief Signal Officer and to other documents bearing on the subject, which can be obtained on application to the War Department.

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CHAPTER VIII.

OPTICS.

SECTION I. — GENERAL PRINCIPLES.

369. Definition of Optics. — OPTICS is that branch of Physics which treats of the phenomena of light.

370. Definition of Light. — Light is that physical agent which, acting upon the eye, produces the sensation of sight.

371. Two Theories of Light. — Two theories have been advanced to account for the phenomena of light: the *Emission Theory*, and the *Undulatory* or *Wave Theory*.

According to the *emission theory*, light consists of infinitely small particles of matter, shot forth from luminous bodies with immense velocity, which, falling on the retina of the eye, produce the sensation of sight.

According to the *undulatory theory*, light, like heat, is caused by the vibrations of the molecules of bodies. It is transmitted by a highly elastic medium called *luminiferous ether*. This medium, which also transmits radiant heat, extends through space, penetrates all bodies, and exists in the intervals between their molecules. The molecular vibrations of a luminous body are imparted to the neighboring ether, and are propagated through it by a succession of spherical waves; these waves, falling on the retina of the eye, excite the sensation of sight.

Light and radiant heat are very closely related to each other, being forms of radiant energy: they are generated in the same manner and

are propagated through the same medium, but they differ from each other in their wave-length, and, as a consequence, in their mode of action on bodies.

Heat is produced by waves of greater length than those which cause light. The vibrations of ether also are more rapid in the case of light.

In sound the particles of air vibrate to and fro in the direction of propagation; in light and radiant heat the particles of ether vibrate to and fro in a direction perpendicular to that of propagation. In sound the vibrations are *longitudinal,* or in the direction of the rays; in light and radiant heat they are *transversal,* or perpendicular to the rays.

The idea of transversal vibrations may be illustrated by a rope made fast at one end and held by the hand at the other. If the free end be moved rapidly to and fro, at right angles to the rope, a succession of waves will run along the rope, while the particles of the rope simply vibrate back and forth in perpendiculars to the rope. If

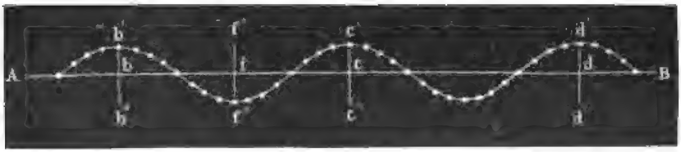

Fig. 235.

a stone be dropped into a pool of still water, a series of waves will be propagated outward, while the particles of water simply rise and fall, their motion being perpendicular to the direction of propagation.

The undulatory theory is now generally accepted by physicists.

This kind of wave motion is shown in Fig. 235. The white dots represent molecules of ether, and the light is supposed to pass in the direction *A B.* The distances *b' c'* and *c' d'* are called wave-lengths, that is, from the crest of one wave to the crest of the next. The distances *b' b''*, *f' f''*, *c' c''*, and *d' d''* represent amplitudes of vibration. Through these distances the molecules of either oscillate back and forth.

372. Luminous Bodies. — Sources of Light. — Bodies that emit light are said to be *luminous;* those that are seen by light derived from others are said to be *illuminated.*

Luminous bodies generate light; illuminated bodies reflect and diffuse it. The sun is a luminous body; the moon is illuminated by it.

The principal sources of light are *the sun*, *the stars*, *heat*, *chemical combination*, *phosphorescence*, and *electricity*.

The ultimate cause of the sun's light is unknown. The sun is surrounded by a gaseous envelope, called the *photosphere*, which appears to be in a state of intense ignition. The molecular vibrations of this envelope are undoubtedly the immediate sources of solar light and solar heat. The stars are similar to the sun, but on account of their enormous distances from us, they send us but a small amount of light and heat.

If a body be heated its molecules are thrown into vibration, and when its temperature reaches 900° or 1000° F., it begins to be luminous in the dark. Beyond that its brightness increases as its temperature rises.

The light developed by chemical combinations is mostly due to the heat that accompanies them. Combustion is an example; the affinity between the oxygen of the air and the carbon of the fuel causes them to rush together under favorable circumstances, thus generating heat and ultimately light itself.

Phosphorescence is the property that some bodies have of giving out light under certain conditions, without heat; it is often observed in decaying animal and vegetable matter, and in some minerals. The light of the fire-fly is an example of this property.

Electricity is the source of a species of light that rivals in intensity that of the sun itself. It will be treated of hereafter.

373. Media. — Opaque and Transparent Bodies. —

A MEDIUM is anything that transmits light; thus, free space, air, water, and glass are *media*.

A medium is said to be homogeneous when the chemical composition and density of all its parts are the same.

A TRANSPARENT BODY is one that permits light to pass through it freely; as glass, diamonds, rock-crystal, and water.

When bodies permit light to pass through them, but not in such quantity as to allow objects to be seen through them,

they are called *translucent.* Thus, scraped horn, ground glass, oiled paper, and thin porcelain are translucent.

An OPAQUE BODY is one that does not permit light to pass through it. Thus, iron, wood, and granite are opaque bodies.

No bodies are perfectly opaque; when cut into sufficiently thin leaves, they are more or less translucent.

374. **Absorption of Light.** — No body is perfectly transparent; all intercept or absorb more or less light, but some absorb much more than others. If light be transmitted through great thicknesses of media which in thin layers are transparent, a quantity of light is absorbed, and it often happens that the transmitted light is not of sufficient intensity to produce the sensation of sight.

The atmosphere seems perfectly transparent, but it is a known fact that much of the light of the sun is absorbed in reaching the earth, as is shown by the greater brilliancy of the stars in the higher regions, as on mountain-tops. In the high regions of the atmosphere objects are more clearly seen than nearer the earth; indeed, so great is the clearness of vision in these regions, that it becomes exceedingly difficult to judge of distances. Opaque bodies absorb all of the light falling upon them which is not reflected.

The physical cause of absorption of light by bodies is some peculiarity of molecular constitution which breaks up and neutralizes the waves of light that enter them.

375. **Rays of Light. — Pencils. — Beams. — Propagation of Light.** — A RAY OF LIGHT is a line along which light is propagated. It is perpendicular to the advancing wave-front. When the source is very distant the wave-fronts are sensibly plane and the rays parallel.

A PENCIL OF RAYS is a small group of rays meeting in a common point, such as the rays proceeding from a candle or a lamp.

When the rays *proceed from* a common point, they are said to be *divergent.* When they *proceed towards* a common point, they are said to be *convergent.*

A Beam of Rays is a small group of parallel rays, such as enter a small hole in a shutter, from a distant body, as the sun.

In a homogeneous medium light is propagated in straight lines. This is proved by placing an opaque body in the straight line that joins the eye on the luminous body; the light is intercepted. The rays of light that pass into a dark room by a small aperture are seen to be straight by the particles of floating dust which they illuminate.

376. Visual Angle. — The angle formed by two lines drawn from the centre of tne eye to the two extremities of the object is called the *visual angle.*

Fig. 236 represents the visual angle. The size of this angle varies with the distance of the body. $A\,B$ and $A'\,B'$ are of the same

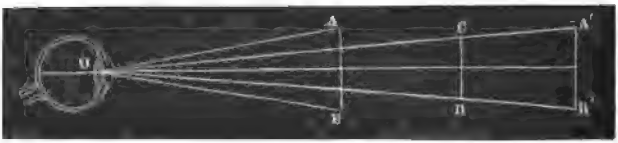

Fig. 236.

length, yet the angle $A\,O\,B$ is larger than $A'\,O\,B'$; hence the apparent size of $A'\,B'$ is less than that of $A\,B$. $C\,D$ has the same visual angle as $A'\,B'$, yet $A'\,B'$ is the larger. The visual angle, then, does not indicate the real size of a body, — we must know its distance. Knowing the size of a body, we can estimate its distance by its visual angle, and knowing the distance we can get its size.

The apparent size of a body can be varied by increasing or decreasing the visual angle. In the formation of images by mirrors and lenses this principle will be illustrated.

377. Shadows. — When light falls upon an opaque body, inasmuch as the rays are transmitted in straight lines, the space behind the body from which the light is excluded is called a *shadow.*

If the source of light be a point, the shadow will be sharply defined; if it be larger than a point, the perfect shadow will

be surrounded by a fainter one called the ***penumbra***. The darker shadow is called the *umbra*.

In Fig. 237 we have these two shadows represented, both the luminous and opaque bodies being spheres. If the luminous surface, *B*, be larger than the opaque body, the umbra will terminate in a point, as in the case of the shadow of *C*. It will be fringed by a penumbra, *D D*.

But if the opaque body is larger than the luminous, the umbra will be divergent, as seen in the shadow of *A*. This is also fringed by a penumbra *D D*.

If the luminous sphere be of the same size as the opaque, the umbra will be a cylinder, with a penumbra for a border.

The penumbra is less dark than the umbra, because only a part of the rays from the luminous body are cut off from the space it occupies.

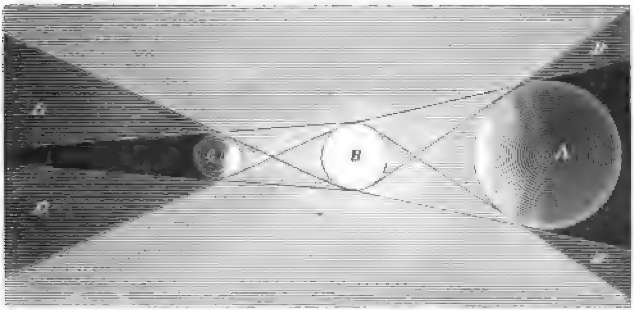

Fig. 237.

378. Velocity of Light. — Light moves with such velocity that for all distances on the earth it is practically instantaneous.

It was shown by Roemer, a Danish astronomer, in 1678, that light occupies nearly $8\frac{1}{4}$ minutes in coming from the sun to the earth, which gives a velocity of 186,000 miles per second.

He ascertained the velocity of light by a succession of observations on the eclipses of Jupiter's first satellite. In Fig. 238, *S* represents the sun, *T* the earth, *J* Jupiter, and

e Jupiter's first satellite, that is, the one nearest to Jupiter. The darkened portion of the figure beyond Jupiter represents the shadow of that planet cast by the sun. It is known by computation that Jupiter's first satellite revolves about that planet once in 42 hours 28 minutes and 36 seconds, and by entering the shadow of Jupiter is eclipsed at each revolution.

ROEMER found that as the earth moved from *T*, its nearest position to Jupiter, towards *t*, its most remote position, the interval between the consecutive eclipses of the satellite gradually grew longer, whilst in moving from *t* back again to *T*, these intervals grew shorter. The total retardation in passing from *T* to *t* was found to be nearly 16½ minutes, and the total acceleration in the remaining half of the earth's revolution was also found to be 16½ minutes. This was accounted for by the fact that the earth was moving away from Jupiter

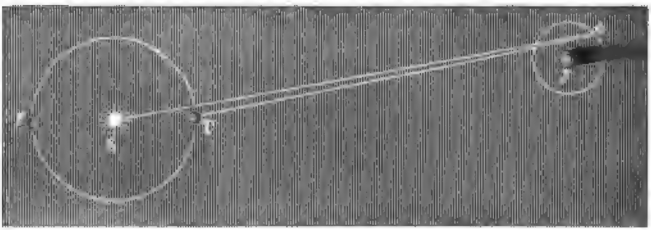

Fig. 238.

in the first case, and therefore the light had to travel farther and farther at each eclipse to reach the observer, while in the second case the reverse happened.

ROEMER therefore inferred that it required 16½ minutes for a ray of light to traverse the diameter of the earth's orbit, or 8¼ minutes for it to pass over the radius of that orbit, that is, over a distance equal to that of the earth from the sun.

It is difficult to conceive a velocity so great as 186,000 miles per second, a speed that would carry a ray of light around the earth eight times in a single second of time. Some idea, however, may be had of the velocity of light from the fact that it would require more than two and a half centuries for one of our most rapid express-

trains of cars to run a distance over which light passes in $8\frac{1}{4}$ minutes.

379. Intensity of Light. — Photometry. — The intensity of light is the amount of disturbance it imparts to the ether. It is *proportional to the square of the amplitude of the vibration of the ether particles ;* that is, as the amplitude increases the intensity increases, as it decreases the intensity also decreases. *The intensity also varies inversely as the square of the distance from its source.*

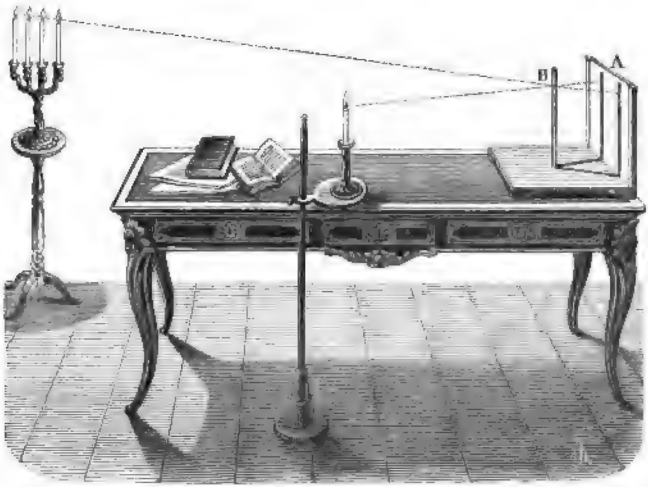

Fig. 239.

Hence we see that light follows the same law with regard to its intensity that is observed for gravity (Fig. 23) and sound. The law of variation of intensity can be verified, experimentally, by means of an instrument called a *photometer*.

A Photometer is an instrument for comparing the intensities of different lights.

Several different instruments have been devised for this purpose, one of the simplest being that shown in Fig. 239.

It consists of a vertical screen of ground glass, *A*, and a vertical solid rod, *B*, situated a short distance in front of it.

If two equal lights are placed at equal distances from *B*, it is found that the shadows which *B* casts upon *A* are of the same tint. If one light be placed at any distance, and four equal lights be placed at twice the distance, the shadows will be of the same tint; this is the case shown in the figure. It will require nine equal lights at three times the distance, sixteen at four times the distance, and so on, to produce the same effect. This experiment confirms the law of variation of intensity according to the inverse square of the distance.

To use the photometer to compare the intensities of any two lights, let them be placed, by trial, at such distances from *B* that the shadows cast on *A* are of exactly the same tint; then will their intensities be to each other as the squares of their distances from the rod, *B*.

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- Definition.
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SECTION II. — REFLECTION OF LIGHT. — MIRRORS.

380. Reflection of Light.—When light passes obliquely from one medium to another, it is separated into two parts, one of which is driven back and remains in the first medium, while the other passes on and enters the second medium. The part that is driven back is said to be *reflected*, and the deviating surface is called a *reflector*.

Reflection of light is explained in the same way as reflection of sound. In case of light the wave-lengths are so small that the most highly polished surfaces are comparatively rough. Hence only a part of the reflected light appears to follow the regular laws; the rest is irregularly reflected or diffused. The amount of light reflected, as well as the relation between that which is regularly and that

which is irregularly reflected, depends on the obliquity of incidence, the nature of the second medium, and the polish of the deviating surface.

Light that is irregularly reflected enables us to see objects; thus, the light falling on a sheet of paper is scattered or diffused so as to render it visible in all directions. If a reflector were perfectly smooth it would be invisible; we should simply see in it the images of other objects.

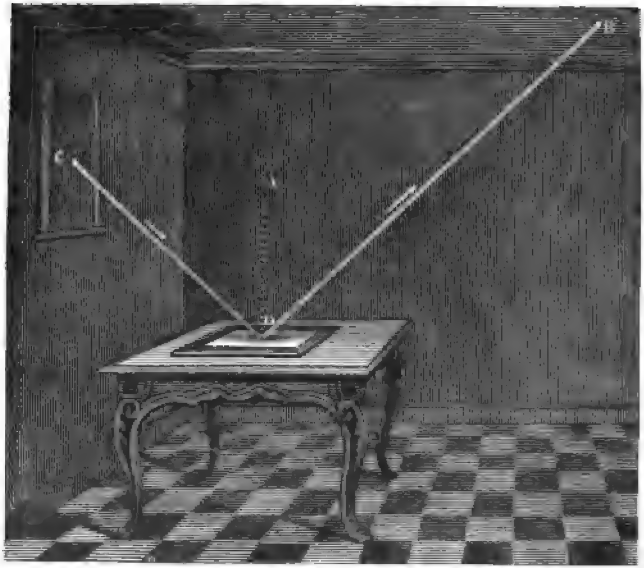

Fig. 240.

It is the diffused light reflected by the clouds, the air, the earth, and objects upon it, that illuminates our rooms, and renders objects visible which do not receive the direct rays of the sun.

If we look out from our houses we see objects clearly by means of this diffused light, because they receive much light and therefore reflect much; but if we look from without into a house we see objects with less distinctness, because they receive but little light, and therefore they reflect but little.

It is now proposed to explain the laws of regular reflection.

381. Definition of Terms. — The ray that falls upon a reflecting surface is called the *incident ray;* thus, CD (Fig. 240) is an incident ray.

The point where the incident ray meets the reflecting surface is called the *point of incidence;* thus, D is a point of incidence.

The angle that the incident ray makes with the perpendicular to the reflecting surface at the point of incidence is called the *angle of incidence;* thus, CDA is an angle of incidence.

The plane that passes through the incident ray and the perpendicular is called the *plane of incidence;* thus, the plane through CD and DA is a plane of incidence.

The ray driven off from the reflecting surface is called the *reflected ray;* thus, DB is a reflected ray.

The angle that the reflected ray makes with the perpendicular is called the *angle of reflection;* thus, BDA is an angle of reflection.

The plane of the reflected ray and the perpendicular is called the *plane of reflection;* thus, the plane of BD and DA is a plane of reflection.

382. Laws of Reflection. — The following laws are shown by theory, and confirmed by experiment: —

1. *The planes of incidence and reflection coincide;* both are perpendicular to the reflecting surface at the point of incidence.

2. *The angles of incidence and reflection are equal;* this is true whatever may be the angle of incidence.

These two laws are illustrated on page 32 (Fig. 18) as regards motion; but the illustration will serve equally well for light with a few changes. Let B represent a mirror, and let a ray of light pass along the line A; it will be reflected at B to C.

It will be seen that the incident and reflected rays lie in the same plane with the perpendicular, BD, or, in other words, that the planes of each coincide.

The plane of these rays is perpendicular to the reflecting surface at *B*.

If the incident ray strikes the reflecting surface at right angles, the reflected ray coincides with the incident.

383. Direction in which Objects are seen. — Whenever the rays of light proceed directly from an object to the eye, we see the body exactly where it is. When by reflection, or any other cause, the rays are bent from their primitive direction, we no longer see bodies in their proper position. They appear to be in the direction from which the ray enters the eye.

This is illustrated in Fig. 241. *A* represents a body from which a ray of light, proceeding in the direction *A B*, is deviated or bent

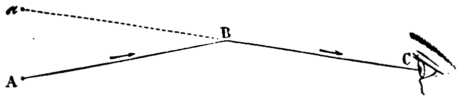

Fig. 241.

at *B*, so as to assume the new direction *B C*. The eye receives the ray from the direction *B C*, and in consequence the object, *A*, appears to be situated at some point, *a*. This principle is of importance in explaining certain phenomena produced by reflectors and lenses.

384. Mirrors. — A MIRROR is a body with a polished surface, employed to form images of objects.

The best reflecting surfaces are those of polished metals. Our ordinary looking-glasses are composed of plates of smooth glass, upon the back of which is fastened a thin layer of tin and quicksilver.

This mixture, called an amalgam, offers an excellent reflecting surface, and it is from this that the principal reflection takes place. The glass serves to give the proper smoothness to the amalgam, as well as to protect it from injury and tarnish. There is, however, a reflection from the outer surface of the glass, giving rise to feeble images, which render such reflectors objectionable for optical purposes. Hence it is, that reflectors for telescopes and the like are generally made

of alloys, or mixtures of hard metals, which admit of a high polish. Such a mirror is called a *speculum*.

385. Plane Mirrors. — A PLANE MIRROR is one in which the reflecting surface is plane.

We have an example of plane mirrors in the ordinary looking-glasses of our houses. The surface of still water, which reflects surrounding objects, and the surface of quicksilver, when at rest, are additional examples.

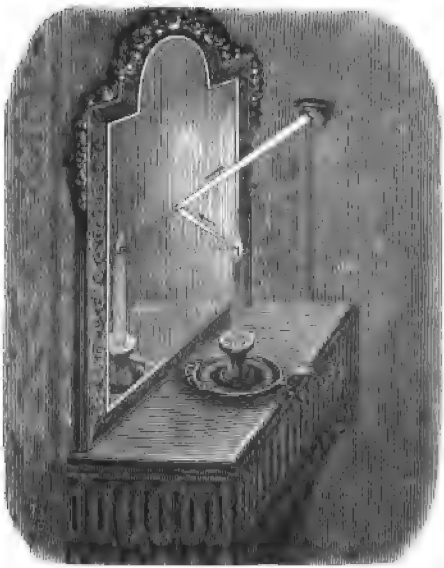

Fig. 242.

386. Images formed by Plane Reflectors. — An IMAGE of an object is a picture or representation of that object, formed by a reflector, or by a lens.

The manner of forming images by plane reflectors is illustrated in Fig. 242. A pencil of rays coming from a point is reflected so as to reach the eye. Because the angles of incidence and reflection are equal (Art. 382), each ray will have

the same inclination to the mirror after reflection that it had before incidence. Hence the reflected rays, on being produced back, will meet at a point as far behind the reflector as the point of the object is in front of it. Now, because the eye sees objects in the direction from which the rays reach it (Art. 383), the point appears to be as far behind the mirror as it really is in front of it. The representation of the point thus formed is its image.

What has been said of a single point is true of all points. Hence, if we suppose pencils of rays to proceed from every point of an object, each point will have its own image as far behind the mirror as the point is in front of it. *The assemblage of images thus formed makes up the image of the object.*

387. **Nature of the Images formed.** — The image of an object in front of a plane mirror is laterally reversed; that is, the right hand of a person becomes the left of the image, and the left hand of the person the right of the image. This comes from the fact that the image of each point is as far behind the mirror as the point is in front.

We see, also, from what has been said, that *the image is erect, and equal in size with the object.*

The rays that reach the eye *appear* to come from an image which does not in reality exist. The image is only *apparent.* Such images are called *virtual.*

A VIRTUAL IMAGE is an image that appears to exist, and which would be found by producing the deviated pencils of rays backward, till they meet in points.

A REAL IMAGE is an image that can be thrown on a screen. It is formed when the reflected rays converge in front of the mirror and on the same side as the object. We shall soon have an example of this kind of image in concave mirrors.

388. **Multiple Images.** — Metallic mirrors, or *specula*, as they are called, having but one reflecting surface, form but a single image. Glass mirrors have two reflecting surfaces, the

front surface of the glass, and the metallic surface at the back of the glass. An image is formed by each of these surfaces, but that formed by the latter is the more striking, because the first surface reflects only a small portion of the light.

This formation of two images by glass mirrors renders them unfit for many optical purposes, as previously stated (Art. 384). The double image, formed by placing a point against the glass, enables us to judge of the thickness of the glass.

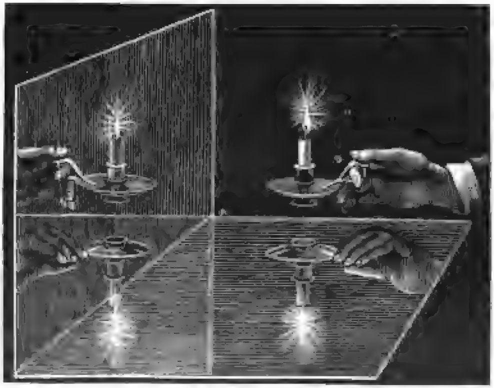

Fig. 243.

If a candle (Fig. 243) be placed between two plane mirrors which form an angle with each other, images of the objects are formed. If the angle is 90°, there will be three images; if 60°, five images; and seven, if it is 45°.

The number of images increases as the angle diminishes. When it becomes zero, that is, when the mirrors are parallel, the number would be infinite, on account of the increasing number of reflections from one mirror to the other. The images, however, become more and more dim as they recede, since each reflection involves a loss of light.

389. **The Kaleidoscope** depends on this property of inclined mirrors. It consists of a tube containing usually three mirrors inclined to one another 60°. One end of the tube is

closed by a cap provided with an aperture for the eye; at the other end there are two plates, one of ground and the other of clear glass, the former being more remote from the eye. Between these two plates of glass small irregular pieces of colored glass are loosely placed.

When we look through the tube, holding the ground-glass end towards the light, the objects and their images are seen arranged in forms of great beauty, which show an endless variety of shapes as we turn the tube.

390. Reflection by Transparent Bodies. — We have just seen that glass, notwithstanding its transparency, reflects light enough to form an image. The same is the case with other transparent bodies, of which water forms a conspicuous example. Images seen in water are symmetrically disposed with respect to the surface of the water, but inverted.

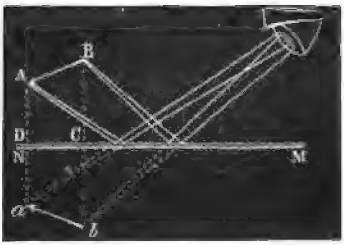

Fig. 244.

The case is precisely the same as though the images had been formed by a horizontal mirror, MN, as represented in Fig. 244. The image, $a\,b$, is seen to be inverted, and as far below the mirror as the object, $A\,B$, is above it.

Fig. 245 represents the phenomenon of reflection from the surface of still water.

391. The Heliostat. — It is necessary, in the illustration of many of the properties of light, to have a beam of sunlight enter a darkened room. This must be direct sunlight, or sunlight reflected from a mirror placed outside the window-shutter.

It is very desirable, also, to have the light reflected in any required direction and for any length of time. To secure this advantage an instrument called a *heliostat* is employed.

This usually consists of a mirror, which is movable, and can be adjusted to the position of the sun at all times, by means of the hand or by clock-work arrangement. The direction of the reflected beam is thus kept unchanged.

A simple and inexpensive heliostat can be made by using two mirrors, one movable, to receive the sun's rays and to reflect them upon a second inclined mirror, which in turn reflects them through an aperture into the darkened room.

Fig. 245

The method of constructing a heliostat of this form is given in detail in Mayer and Barnard's book on Light.

Dolbear's "Art of Projecting" also gives directions for making one at a trifling cost that will answer every purpose.

This apparatus is of great use in many experiments in physics. The name *heliostat* is generally given to the instrument when it has a clock-work arrangement for moving the mirror, and *porte lumière* to the simpler form, where the mirror is adjusted by the hand.

392. Concave Mirrors. — A CONCAVE MIRROR is one in which the reflection takes place from the concave side of a curved surface.

We shall consider the case in which the reflecting surface is a segment of a sphere.

The following definitions apply equally to concave and convex mirrors: —

The middle point of the mirror is called its *vertex*. The centre of the sphere, of which the mirror forms a part, is called the *centre of curvature*. The indefinite straight line through the centre of curvature and the vertex is called the *principal axis*, or sometimes simply the *axis*. Any plane section through the axis is called a *principal section*.

Thus, *MN* (Fig. 246) represents a principal section of a concave mirror, *A* is its vertex, *C* its centre of curvature, and *A L* its principal axis.

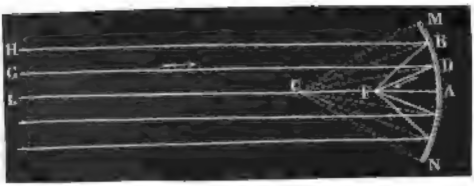

Fig. 246.

393. Principal Focus of a Concave Mirror. — A Focus is a point at which deviated rays meet. If the incident rays are parallel to the axis, the focus is called the *principal focus*, as *F*; and the distance from the vertex to the principal focus is called the principal *focal distance*, as *FA*.

In Fig. 246, *H*, *G*, and *L* are rays parallel to the axis. *C A*, *C D*, *C B*, and *C M* are perpendicular to the surface of the mirror, being radii. The parallel rays, *H*, *G*, and *L*, are reflected so as to make the angles of incidence equal to those of reflection, that is, *C B H* equal to *C B F*, *C D G* to *C D F*, etc. It can be shown that the principal focus is on the axis, and midway between the vertex and centre of curvature. We shall always designate the principal focus by the letter *F*.

If the luminous point is not situated on the principal axis of the mirror, a line drawn from this point through the centre of curvature will constitute a *secondary axis,* and the focus of the reflected rays will be on this axis.

It is to be observed that in practice the surface of a curved mirror is only a very small part of the surface of the sphere of which it forms a part.

Unless this be the case we shall not secure accuracy of reflection, because the rays reflected from the borders of the mirror and those from portions nearer the vertex will not be brought exactly to the

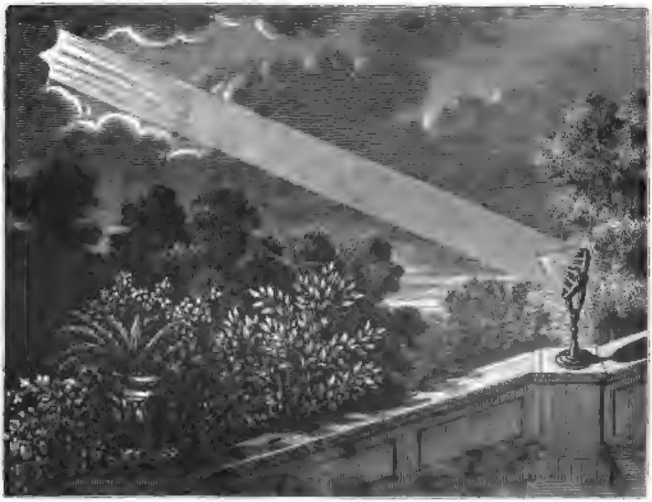

Fig. 247.

same focus. The outer rays are reflected nearer to the mirror than the inner ones. This inaccuracy is called *spherical aberration by reflection.*

Parabolic mirrors reflect without aberration, and are used where intense light is desired at a great distance, as in the headlight of a locomotive.

Fig. 247 shows the manner of determining the principal focus by experiment, making use of a beam of light coming from the sun. In this form the concave reflector may be used to collect the rays for the purpose of developing a great amount of heat.

394. Conjugate Foci. — If the rays of light emanate from some point of the axis not infinitely distant from the mirror, they will be brought to a focus at some point of the axis, generally different from F. Thus, in Fig. 248, the pencil of rays coming from the point B is brought to a focus at b, between F and C. Had the rays emanated from b, they would have been brought to a focus at B. These points are so related as to receive the name of *conjugate foci*. Hence we have the following definition: —

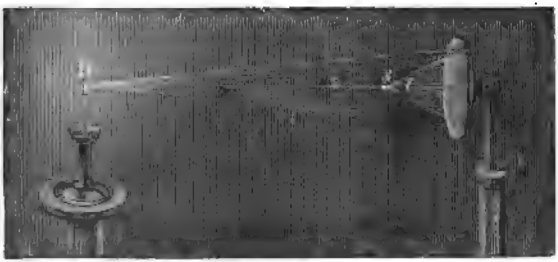

Fig. 248.

CONJUGATE FOCI are any two points so related that a pencil of light emanating from either one is brought to a focus at the other.

That one from which the light actually proceeds is called the *radiant*; thus, in Fig. 248, B is the radiant.

The following are some properties of conjugate foci of concave mirrors: —

If the radiant is on the axis and at an infinite distance from the mirror, the rays will be parallel and the corresponding focus is at F (Fig. 246).

As the radiant approaches the mirror, the focus recedes from it.

If the radiant is beyond the centre of curvature, C, the focus is between F and C.

If the radiant is at C, the focus is at C also.

If the radiant is between C and F, the focus is beyond C, he direction $C\ L$.

If the radiant is at F, the focus is at an infinite distance; that is, the reflected rays are parallel.

If the radiant is between F and A, as shown in Fig. 249,

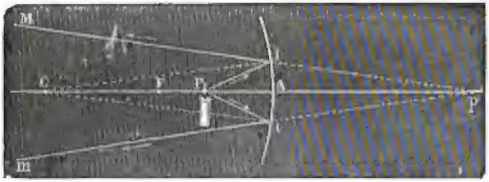

Fig. 249.

the rays are reflected so as to diverge, and on being produced backwards, meet at p. In this case the focus is behind the mirror, and is said to be *virtual.*

If the radiant is at A, the focus coincides with it.

If the radiant is on a secondary axis, the pencil of rays is oblique, but it is still brought to a focus on that axis, and the radiant and focus enjoy properties entirely analogous to those just explained.

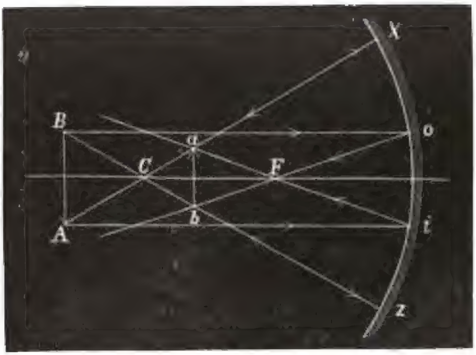

Fig. 250.

395. Formation of Images by Concave Reflectors.—If an object be placed in front of a concave mirror, a pencil of rays will proceed from each point of the object, which

after reflection will be brought to a focus, either real or virtual. The collection of foci thus formed make up the *image of the object.*

Let $A\ B$ (Fig. 250) be an object in front of a concave mirror beyond the centre of curvature. All the rays that diverge from A will be reflected to its conjugate focus, a, which is on the secondary axis, $A\ x$. This point can be found by draw-

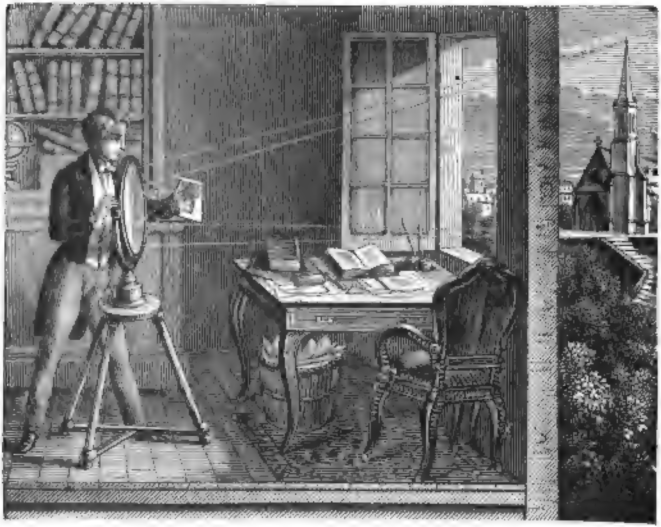

Fig. 251.

ing $A\ i$ parallel to the principal axis; it will pass after reflection through F and cut $A\ x$ at a, the point required.

By a similar process we can find the conjugate focus, b, for the point, B, or for any other point of the object. The collection of foci forms the image, $a\ b$.

After the reflected rays form the image, $a\ b$, they come from this image to the eye, just as if it were a real object. That the image is real may be shown by throwing it on a screen (Fig. 251); it will also be seen that the rays by crossing invert it.

The direction which the rays assume after reflection makes the image smaller than the object.

As the object approaches the mirror, the image recedes from it; when the object is at the centre of curvature, the image will be the same size as the object; when it is between the centre and principal focus, the image is larger; in both these instances we shall find the image real and inverted.

When the object is at the principal focus, there will be no image, since the reflected rays are parallel.

396. Virtual Images. — When the object is between the principal focus and the mirror, the image is virtual and erect, and larger than the object, or magnified.

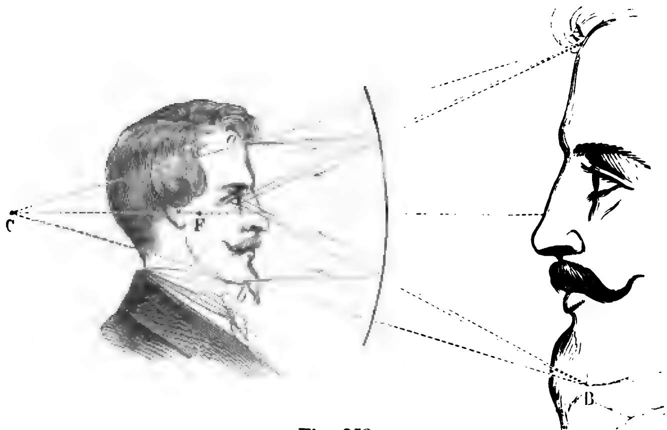

Fig. 252.

Fig. 352 shows the course of the rays in forming a virtual and erect image. The face is between the principal focus, *F*, and the mirror. The pencils of rays from *a* and *b* are reflected so as to appear to diverge from the virtual foci, *A* and *B*. It is easily seen that the image is larger than the object, by a comparison of the visual angles of both.

397. Formation of Images by Convex Reflectors. — In convex mirrors the reflection takes place from the outer or convex surface.

From what has been said of concave mirrors, it will readily

be seen how images are formed by convex mirrors. The images formed in this case are always virtual, always erect, and always smaller than the object, as is shown in Fig. 253.

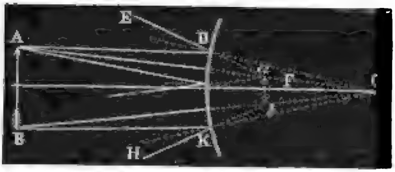

Fig. 253.

The parallel rays, *A D* and *B K*, are reflected as the divergent rays, *E D* and *H K*. When these rays enter the eye, the image is seen at *a b*.

Summary.—

Reflection of Light.
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- Diffused Light.

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- Illustrated by Figures.

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- Materials of which Mirrors are made.

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- Examples of Plane Mirrors.

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- Formation of an Image.

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Reflection by Transparent Bodies.
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Use and Description.
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Illustrated by Figure.

SECTION III. — REFRACTION OF LIGHT. — LENSES.

398. It was stated under *Reflection of Light*, that when light passes obliquely from one medium to another, it is separated into two parts, one of which is driven back or reflected, and remains in the first medium, while the other passes on and enters the second medium. If the substance that forms the second medium is opaque, it is *absorbed*, but, if transparent, some is absorbed and some transmitted. The transmitted rays change direction at the point of incidence. This change of direction is called *refraction*. Its amount depends on the nature of the media, and also on the obliquity of incidence.

If the incident ray is perpendicular to the second medium, it is not bent from its course.

The cause of this change of direction is a change in the elasticity and density of the ether in passing from one medium into the other, which causes a change in the velocity of the ray. Thus, the density

and elasticity of ether in water are different from what they are in the atmosphere, so that light travels considerably faster in the latter medium than in the former. This causes a ray, on passing from air into water, to bend towards the perpendicular at the point of incidence, as shown in Fig. 254. Thus, $L\ A$ is bent from its course so as to take the direction $A\ K$. In passing from water to air, the ray is bent away from the perpendicular, just the reverse of what happens when light passes from air into water.

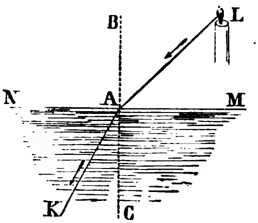

Fig. 254.

399. Definition of Terms. — The ray before refraction is called the *incident ray*; thus, $L\ A$ (Fig. 254) is an incident ray.

The point at which the ray is deviated or bent is called the *point of incidence*; thus, A is a point of incidence.

The ray after deviation is called the *refracted ray*; thus, $A\ K$ is a refracted ray.

The angle that the incident ray makes with the perpendicular at the point of incidence is called the *angle of incidence*, and the plane of this angle is the *plane of incidence*. Thus, $L\ A\ B$ is an angle of incidence, and the plane, $L\ A\ B$, is the plane of incidence.

The angle that the refracted ray makes with the perpendicular at the point of incidence is called the *angle of refraction*, and the plane of this angle is the *plane of refraction*; thus, the angle, $K\ A\ C$, is an angle of refraction, and the plane of this angle is a plane of refraction.

400. Refractive Power of Bodies. — In the case of two media through which light is passing, that in which the ray makes the smaller angle with the perpendicular is said to have greater refractive power than the other.

As a general rule, the incident ray, when passing obliquely from a rarer to a denser medium, bends towards the perpendicular; when passing from a denser to a rarer, it bends from the perpen-

dicular; or, in other words, the denser of two substances has the greater refracting power.

NEWTON observed that, as a general rule, the refractive power was greatest for combustible bodies, or bodies containing combustible elements, such as alcohol, ether, oils, etc., which contain both hydrogen and carbon. He found that the diamond was more highly refractive than any other body, and hence inferred that it was a combustible body, — an inference that has since been confirmed. It is to its high refractive power that the diamond owes its brilliancy as a jewel. Gases are not so highly refractive as liquids, but their refractive power may be increased by compression, which augments their density.

401. Laws of Refraction. — When light passes from any given medium into another, no matter what may be the angle of incidence, it always conforms to the following laws: —

1. *The planes of incidence and refraction coincide, both being perpendicular to the surface separating the media, at the point of incidence.*

2. *The sine of the angle of incidence divided by the sine of the angle of refraction is a constant quantity for the same two media, but varies for different media.*

This constant quantity is called the *index of refraction.*

The second law may be illustrated by Fig. 255. Let I be the point of incidence on a surface separating air from water. With I as a centre, describe a circle, $R'PS$. Let IR be an incident ray, and SI the refracted ray. Draw $P'R'$ and SP perpendicular to the line $P'P$. Then will these lines be the sines of the angles of incidence and refraction, and we shall have for the index of refraction when light passes from air into water the ratio $\frac{4}{3}$, from air into glass, $\frac{3}{2}$. The reciprocals of these fractions will

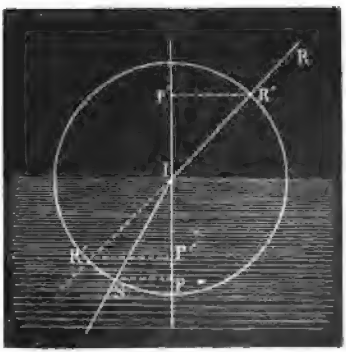

Fig. 255.

give the indices of refraction when light goes in the opposite direction; thus, from water to air it is $\frac{3}{4}$, and from glass to air $\frac{2}{3}$. These fractions represent the *relative* indices of refraction for the two media.

When a ray passes from a vacuum into any medium, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is always greater than unity, and is called the *absolute index of refraction*, or simply the *index of refraction* for the given medium. This index is generally expressed decimally. Thus, for ice, it is 1.309; for alcohol, 1.372; and so on.

Fig. 256.

402. Experimental Proofs of Refraction. — If a beam of light be introduced through a hole in a shutter of a dark room, and allowed to fall upon the surface of water in a glass vessel, as shown in Fig. 256, the bending of the beam as it enters the water may be seen by the eye. The course of a ray in the air may be rendered more apparent by filling

the air with fine dust or smoke, as, for example, the smoke from gunpowder.

Let a piece of money be placed at the bottom of an empty vessel, and then take a position such that the coin shall just be hidden by the side of the vessel. While in this position, if water be poured into the vessel, the rays from the coin will be refracted so as to render it visible. The effect of refraction in this and similar cases is to make the bottom of the vessel appear higher than it is in reality, as shown in Fig. 257.

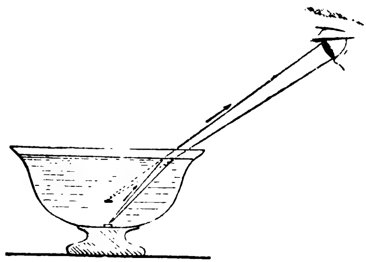

Fig. 257.

403. One of the effects of refraction was explained in the last article. The principle has numerous applications. To a person standing on the shore, a fish in the water appears higher than his real position. If a stick be partially plunged into water, the portion immersed will be thrown up by refraction, and the stick will appear bent, as shown in Fig. 258.

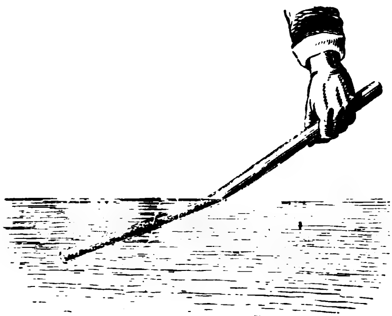

Fig. 258.

Refraction has the effect to make the heavenly bodies

appear higher than they are, and thereby causes them to rise earlier and set later than they would do were there no atmosphere.

This can be seen by inspecting Fig. 259. The layers of the atmosphere are denser as they are nearer the earth, and as the refractive power of a gas increases with its density the rays are bent in a curved line to the eye. The heavenly body, *S*, is seen in the position, *S′*. The eye refers its position along the line *A S′*.

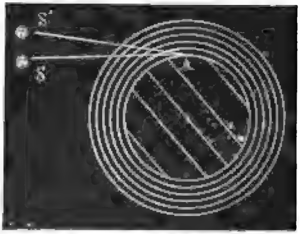
Fig. 259.

To understand the apparent changes in position of bodies when refraction takes place, we must remember that the *object is seen in the direction of the refracted ray as it enters the eye.*

404. Total Reflection. — Critical Angle. — If light fall on a surface that separates a medium from one that is less refractive, there is a limit beyond which it will not pass from the first medium into the second, at that limit light is *totally* reflected.

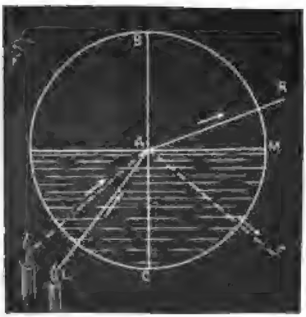
Fig. 260

Let *B M C* (Fig. 260) be a glass globe half full of water. The ray, *L A*, being perpendicular to the globe, is not refracted in entering, but if the angle, *C A L*, be small enough, it is refracted at *A*, taking the direction, *A R*. If the angle of incidence be increased, the angle of refraction will also be increased until it becomes a right angle, or 90°. The refracted ray, *A M*, then emerges parallel to the surface of the water. The incident angle in this case is called the *critical* angle, since for any greater angle, as *l A C*, the incident ray can no longer pass through the surface, *A M*, but is totally reflected and remains in the first medium, taking the direction, *A r*.

From water to air the critical angle is 48° 35′; from glass to air, about 41°.

405. Examples of Total Reflection. — The phenomenon of total reflection may be shown in various ways. If a glass of water with a spoon in it be held above the level of the eye, and we look up obliquely at the surface of the water, the under side of the surface will shine like a polished mirror; the lower portion of the spoon will be totally reflected in it, as seen in Fig. 261.

Fig. 261.

Let a ray of light (Fig. 262) fall perpendicularly upon the side, *A C*, of the glass prism, *A C B*; it will form an angle of 45° with the side, *A B*. This being greater than the critical angle of glass, the ray will be totally reflected in the direction, *H O*.

The prism represented in the figure has the form of a right-angled isosceles triangle.

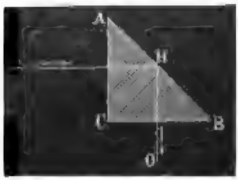

Fig. 262.

406. Mirage is an atmospheric phenomenon dependent on extraordinary refraction and total reflection.

Sometimes a layer of atmosphere next the earth becomes a reflector, and in that case portions of the earth appear to the traveller like lakes and ponds; such appearances are frequent in desert countries when the heat is intense. To heighten the illusion, trees are often seen reflected from the surfaces of these apparent ponds. An example of this kind is shown in Fig. 263. The layers of air near the ground are more heated than those higher up, and therefore less dense. The rays coming from the top of the tree on the left of the

picture are refracted as they pass through the successive strata until they are totally reflected at a, from a layer of the atmosphere, and reach the eye of the observer at the tent. The observer refers the position of the tree-top backwards along the direction of the dotted line, which causes the tree to appear inverted. In this case both the tree and its image are seen.

Images of distant shores or ships are sometimes seen in the air at sea. This form of mirage is the reverse of that just given. Here the layers near the water are denser than those above.

Fig. 263.

The phenomenon of mirage may be shown in a very simple way. If we look along the side of a red-hot poker or a mass of glowing charcoal at an object a few feet off, we shall see at a short distance from either an inverted image.

Summary.—

Refraction of Light.

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Rules for the passage of Light into Media of Different Density.

Comparative Refractive Power of Different Bodies.

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Total Reflection.
Illustrated by Figure.
Critical Angle.
Examples of Total Reflection.
With Spoon and Tumbler.
With Prism.
In Cases of Mirage.

407. Media with Parallel Faces. — When a ray of light, *SA*, Fig. 264, falls upon a medium bounded by plane faces, as a plate of glass, for example, it is refracted towards the perpendicular and passes through the plate; as it emerges at *D*, it is refracted as much from the perpendicular as it was towards it in the first instance, and the ray emerges in the direction, *DB*, parallel to *SA*, but not in the same straight line with it. The two refractions do not change the direction of the ray, but simply shift it slightly to one side or the other. Hence, in looking through a window, we do not see the direction of objects changed by the intervening glass.

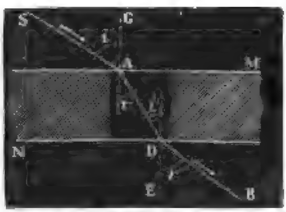

Fig. 264.

GA and *DE* represent the perpendiculars, $i\,i'$ the angles of incidence, and $r\,r'$ the angles of refraction.

408. Prisms. — A PRISM is a refractive medium bounded by plane faces intersecting each other.

Fig. 265 represents a prism mounted for optical experi-

ments. It consists of a piece of glass with three plane faces, meeting in parallel lines called *edges*. It is placed on a stand so that it can be elevated or depressed, and it also is capable of being turned around an axis parallel to the edges, by means of a button shown on the left.

Fig. 265.

Prisms produce upon light which traverses them two remarkable effects: 1st, *a considerable deviation;* 2d, *a decomposition of light* into its elements.

These effects are simultaneous; but we shall at present only consider the first one, leaving the second to be studied hereafter under the name of *Dispersion*.

409. Course of Luminous Rays in a Prism. — In order to follow the course of a ray of light in passing through a prism, let $n\,m\,o$ (Fig. 266) represent a section of a prism made by a plane perpendicular to the edges. A ray of light, $L\,a$, falling upon the face, $n\,m$, is refracted towards the perpendicular, and passes through the prism in the direction, $a\,b$; here it falls upon the second face, $m\,o$, and is again refracted, but

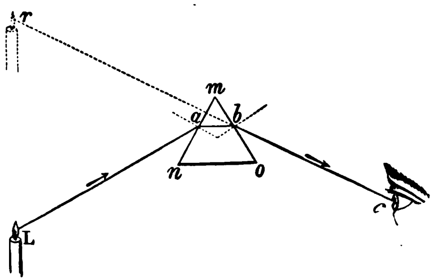

Fig. 266.

this time from the perpendicular, and emerging into the air, takes the direction, bc. An eye situated at c refers the object, L, backwards along the ray, cb, so that it appears to be situated at r. The total deviation is the angle between its original direction, La, and its final direction, cr.

We see from the figure that the ray is bent from the edge in which the refracting faces meet; that is, it is bent towards the thick part of the prism; this deviation has the effect to make the object appear as though thrown towards that edge. The angle, nmo, is called the refracting angle of the prism.

410. Lenses. — A Lens is a refracting medium, bounded by curved surfaces, or by one curved and one plane surface.

Lenses are usually made of glass, and are bounded by spherical surfaces, or by one spherical and one plane surface. The surfaces are made spherical, because they are more easily wrought by the glass-grinder.

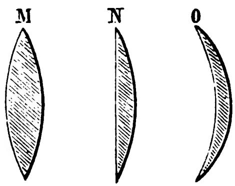

Fig. 267.

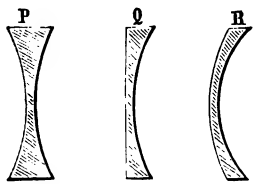

Fig. 268.

411. Classification of Lenses. — Lenses are divided into six classes, according to the nature and position of the bounding surfaces, sections of which are shown in Figs. 267 and 268.

The first three, represented in Fig. 267, are thicker in the middle than at their edges. These *converge* or collect rays of light, and are called *convergent* lenses.

The last three are thinner in the middle than at their edges. These *diverge* or scatter rays of light, and are called *divergent* lenses.

1. The *double-convex* lens, *M*, bounded by two convex surfaces; 2. The *plano-convex* lens, *N*, bounded by one convex

and one plane surface; 3. The *meniscus*, *O*, bounded by one concave and one convex surface, the concave surface being the *least* curved; 4. The *double-concave* lens, *P*, bounded by two concave surfaces; 5. The *plano-concave* lens, *Q*, bounded by one concave and one plane surface; 6. The *concavo-convex* lens, *R*, bounded by one concave and one convex surface, the concave surface being the *most* curved.

In studying the effect of these lenses, it will be sufficient to consider the *double-convex* and the *double-concave* lenses as specimens of the classes to which they belong, the former representing the *convergent*, and the latter the *divergent* classes.

412. Definition of Terms. — The centres of the bounding surfaces of a lens are called *Centres of Curvature;* thus, in Fig. 269, *c* and *C* are centres of curvature.

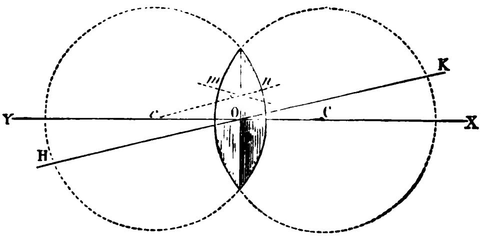

Fig. 269.

In the double convex lens the centre of curvature of each surface is on the opposite side of the lens; in the double-concave lens the reverse is the case. In the meniscus and the concavo-convex lens both centres are on the same side of the lens. In the plano-convex and the plano-concave lens the centre of curvature of the plane surface is at an infinite distance, and in a perpendicular to the plane surface at its middle point.

The straight line through the centres of curvature is called the *axis* of the lens; thus, in Fig. 269, *X Y* is the axis.

It is demonstrated in higher optics, that there is always one point on the axis of a lens, such that the rays of light passing through it are not deviated by the lens. This point

is called the *optical centre*, and is of much use in the construction of images.

In practice it is usual to make the surfaces which bound double-convex and double-concave lenses equally curved.

When this is the case, as we shall suppose in what follows, the optical centre is on the axis, and midway between the two surfaces of the lens; thus, in Fig. 269, O is the optical centre, and any ray, HK, passing through it, is not deviated by the lens.

To find a normal at any point of the surface of a lens, we draw a line from that point to the corresponding centre of curvature; thus, $m\,C$ and $n\,c$ are normals at the points m and n.

413. Action of Convex Lenses on Light.—When a ray of light falls upon one surface of a double-convex lens, it is refracted towards the normal, passes through the lens, is again incident upon the second surface, and is refracted from the normal. This action is entirely analogous to that of a prism, the deviation being towards the thicker portion in both cases. In fact, if we suppose planes to be drawn tangent to the surfaces at the points of incidence and emergence, they may be regarded as the faces of a prism through which the ray passes.

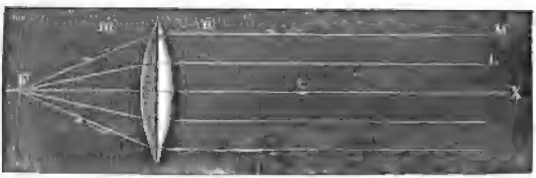

Fig. 270.

414. Principal Focus.—If a beam of light parallel to the axis falls upon a lens, it will be collected by refraction in a single point. This point is called the *principal focus*, and its distance from the lens is called the *principal focal distance*.

The course of the rays is indicated in Fig. 270, in which the rays parallel to CX are brought to a focus at F. Here F is the principal focus.

Since the rays that pass through the edge of a spherical lens are refracted more than those passing nearer the centre, they cannot be brought accurately to the same focus, except in the case in which the surface of the lens is small, when compared with that of the whole sphere of which it forms part. This scattering of the rays from a focus is called *spherical aberration* by refraction. It is remedied in practice by covering up a part of the surface on which light falls, by a paper cover with an *aperture* in its centre.

Had the rays fallen upon the other side of the lens, they would have been brought to a focus as far to the right of the lens as F is to the left of it.

Fig. 271.

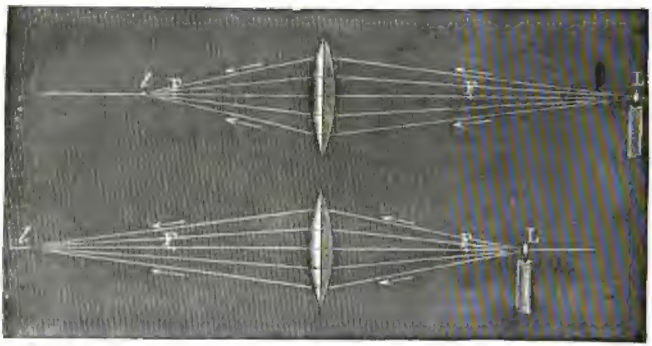

Fig. 272.

415. Conjugate Foci are any two points so situated on the axis of a lens that a pencil of light coming from one is brought to a focus at the other. That from which the light actually comes is called the *radiant*.

In Fig. 271 a pencil of rays coming from L is brought to a focus at l; had the light come from l, it would have been brought to a focus at L; L and l are conjugate foci, and in the case figured, L is the radiant.

When the radiant is at an infinite distance, the rays are

parallel, and the corresponding focus is at *F;* this is the *principal focus.* As we have already seen, there are two such foci, one on each side of the lens. It will be sufficient for our purpose to suppose the light to come from the right, in which case the principal focus is on the left, at *F*.

When the radiant is anywhere on the axis at a greater distance than the principal focal distance, the corresponding focus will also be at a greater distance from the lens than the principal focal distance, as shown in Fig. 271.

If the radiant approach the lens, the corresponding focus will recede from it, as is shown in Fig. 272.

If the radiant is at the principal focal distance, the re-

Fig. 273.

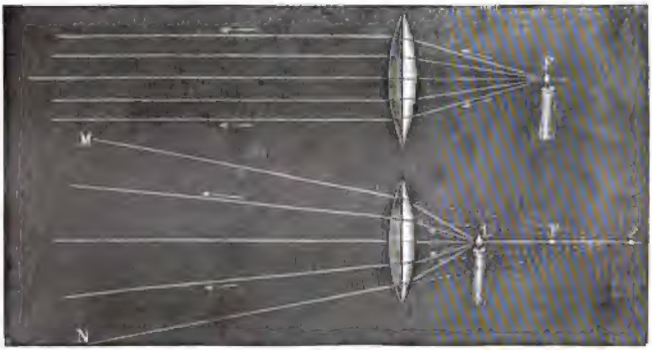

Fig. 274.

fracted rays will be parallel; that is, the corresponding focus will be at an infinite distance, as is shown in the upper diagram (Fig. 273).

If the radiant is still nearer the lens, the rays will diverge after deviation, and will only meet the axis on being produced backwards, in which case the focus is *virtual*, as is shown in the lower diagram (Fig. 274). In this diagram *L* is the radiant, and *l* the virtual focus.

Thus far we have supposed the radiant to be situated on

the principal axis; if it is on any line through the optical centre not much inclined to the axis, the corresponding focus will be on that line, and the laws which regulate the positions of conjugate foci, already considered, will be applicable. Such a line is called a secondary axis.

The principles just illustrated are of use in the discussion of images formed by lenses.

416. Formation of Images by Convex Lenses. — If an object be placed in front of a lens, each point of it may be regarded as a radiant sending out a pencil of rays. Each pencil is brought to a focus somewhere behind the lens. The assemblage of these foci makes up a picture of the object, which is called its *image*. When the object is at a greater

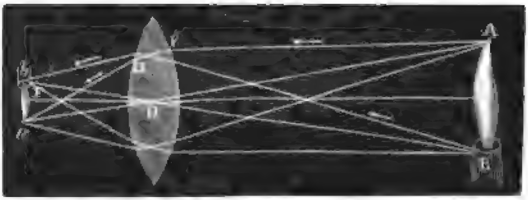

Fig. 275.

distance from the lens than the principal focal distance, the image will be real and inverted.

The course of the rays is shown in Fig. 275. The image is real, as may be shown by throwing it upon a screen; so long as the image is real it is inverted, as may be seen by allowing it to fall upon a screen, or it may otherwise be shown from the fact that the axis of each pencil passes through the optical centre; hence the image of each point is on the opposite side of the axis from the point.

With respect to the size of the image in this case, it may be either greater or smaller than the object. When the object is farther from the lens than twice the principal focal distance, the image is smaller than the object; when the object is at twice the focal distance, the image is of the same size

as the object; when the distance is less than twice the principal focal distance, and greater than the principal focal distance, the image is greater than the object.

These principles may be shown experimentally as follows: —

Let a convex lens be placed in a dark room, and suppose its principal focal distance to have been determined by means of a beam of solar rays. Let a candle be placed in front of the lens, and a screen behind it to receive its image, as shown in Fig. 276.

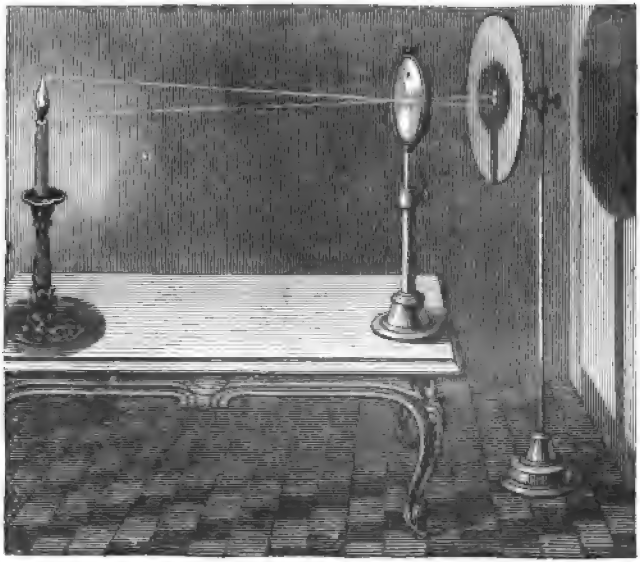

Fig. 276.

When the distance of the candle from the lens is more than twice the principal focal distance, its image will be less than the object; and the more remote the candle the less will be its image.

If the candle be moved towards the lens, its image will grow larger, until, at twice the principal focal distance, the size of the image and object will be equal.

If the candle be moved still nearer, the size of the image will be increased; that is, it will become greater than the object, as is shown in Fig. 277.

If the distance of the object does not become smaller than the principal focal distance, the image will be inverted, as is shown in Figs. 276 and 277.

If the object approach still nearer the lens, that is, if its distance becomes less than the principal focal distance, the image will increase, it will become erect, and furthermore it will be virtual. The course of the rays in this case is shown in Fig. 278. Here AB is the object, and ab is its image, which can only be seen by looking through the lens.

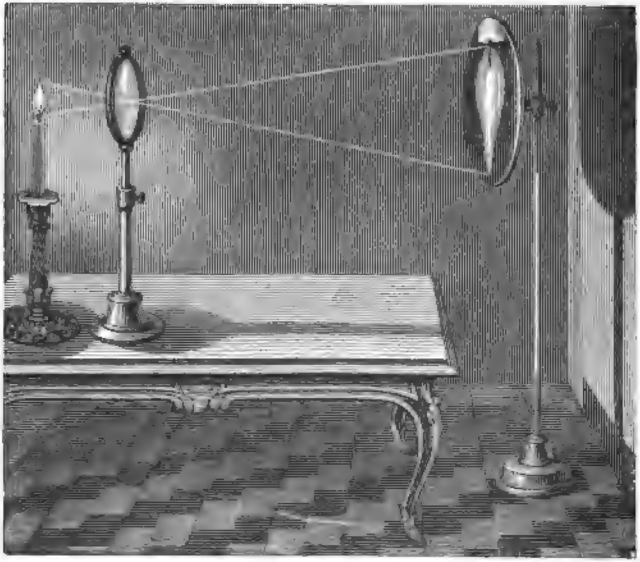

Fig. 277.

In this case the lens becomes what is called a *single microscope.*

When the object is at the principal focal distance from the lens, the image is infinite; that is, it disappears.

The phenomena just described may be observed by looking through a convex lens at the letters on a printed page. When the letters are at a short distance from the lens, they are magnified and erect; on removing the lens farther from the page, they disappear at the principal focal distance, and finally reappear inverted and diminished in size.

417. Formation of Images by Concave Lenses. — Concave lenses, being thinner in the middle than at the edges, have the effect to diverge parallel rays. If the rays are already divergent, these lenses make them still more so.

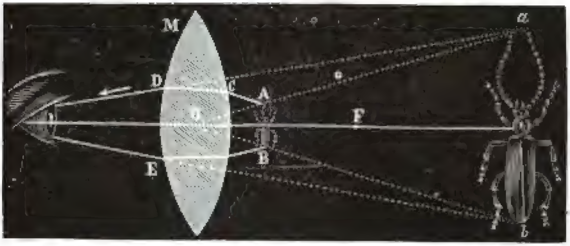

Fig. 278.

This is shown in Fig. 279, in which a pencil of rays, coming from the radiant, *L*, is made to diverge, as though they proceeded from a point, *l*, nearer the lens. This point, *l*, is the virtual focus, corresponding to the radiant, *L*. To an eye situated on the left of the lens, the light, *L*, appears to be situated at *l*.

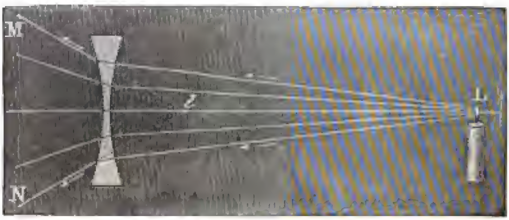

Fig. 279.

From what has been said, it is plain that the images formed by concave lenses are virtual. They are also erect, as in Fig. 279.

The course of the rays, in forming an image in the case of a concave lens, is shown in Fig. 280. In that figure *A B* represents the object. A pencil of rays, coming from *A*, is deviated so as to appear to come from *a*, situated on a line

drawn from A to the optical centre of the lens, O. A pencil, coming from B, is deviated so as to appear to come from b, on the line Bo. Hence ab is the image of the object, AB, and is, as we see, smaller than the object, being nearer the optical centre, and furthermore it is erect.

418. Burning-Glasses. — Rays of heat are subject to the same laws of reflection and refraction as rays of light. When a beam of solar light falls upon a convex lens, there is not only a concentration of light at the focus, but of heat also.

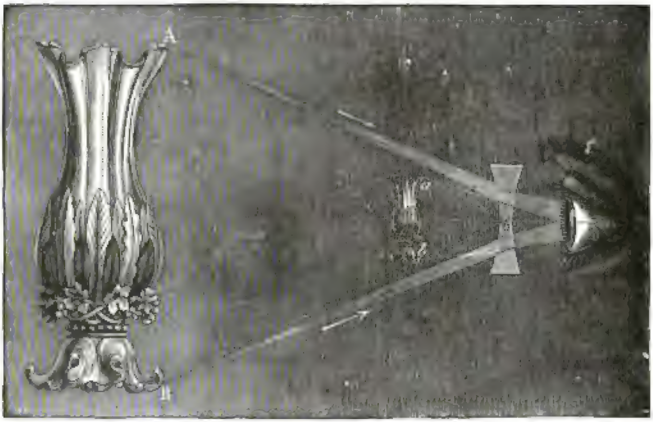

Fig. 280.

The heat concentrated is so great as to inflame combustible bodies, such as paper, cloth, wood, and the like. In the case of large lenses the heat becomes sufficiently powerful to fuse metals. This property of lenses has been used to procure fire; the lens in this case is called a *burning-glass*. Lenses carelessly exposed may sometimes cause dangerous results, by setting fire to inflammable materials. This effect may result from spherical vessels of glass filled with water, which possess all the properties of lenses.

419. Lighthouse Lenses. — Parabolic mirrors were formerly used in lighthouses. These, however, soon became

tarnished by the influence of sea-fogs, and have been supplanted by plano-convex lenses. In the case of reflectors, the lamp itself cuts off considerable light. In the principal foci of the lenses powerful lamps are placed so that the emergent rays form a parallel beam, which enables the light to be seen at a distance of many miles.

The difficulty of constructing large plano-convex lenses, together with their great absorption of light, led finally to the adoption of a particular system of lenses, known as *échelon lenses*.

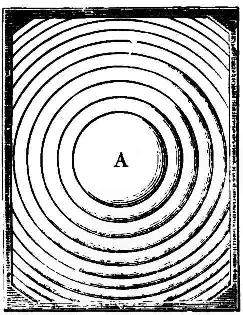

Fig. 281

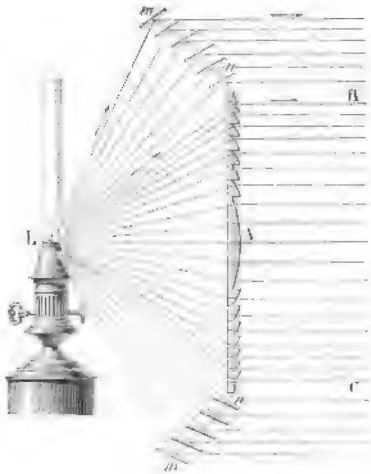

Fig. 282.

Fig. 281 shows a front view, and Fig. 282 a section or profile of an échelon lens.

A lens of this kind consists of a plano-convex lens, A, about a foot in diameter, around which are disposed several annular lenses, which are also plano-convex, and whose curvature is so calculated that each one shall have the same principal focus as the central lens, A.

A lamp, L, being placed at the principal focus of this refracting system, as shown in Fig. 282, the light emanating from it is refracted into an immense beam, $R\,C$, of parallel rays.

Besides this refracting system, several ranges of reflectors, $m\,n$, are

so disposed as to reflect such light as would otherwise be lost, to increase the beam of light formed by refraction.

In order that all the points of the horizon may be illuminated, a system of these lenses is made to revolve on a vertical axis by clockwork.

In consequence of this rotation, an observer at any point will see flashes of light and intervals of darkness following each other alternately. By suitably regulating the number of revolutions in any given time, different lighthouses may be distinguished from each other. These alternations also serve to distinguish lighthouses from a star or accidental fire.

The electric light is used at the present time to some extent in lighthouses, the electricity being generated by magneto-electric machines operated by steam.

Summary. —

Media with Parallel Faces.

Illustrated by Figure.

Prisms.

Definition.

Mounted Prism explained by Figure.

Effect of Prisms on Light.

Course of Luminous Rays in a Prism.

Illustrated by Figure.

Lenses.

Definition, and how made.

Classification of Lenses.

Definition of Terms.

Illustration, by Figure, of Terms used.

Action of Convex Lenses on Light.

Comparison of Convex Lenses with Prisms.

Principal Focus illustrated by Figure.

Spherical Aberration.

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Different Positions of the Focus and Radiant.

Formation of Images by Convex Lenses.

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Methods of forming Real Images illustrated by Figure.

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Formation of Images by Concave Lenses.
    Illustrated by Figure.
Explanation of Burning-Glasses.
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    Use of the Electric Light.

SECTION IV. — DECOMPOSITION OF LIGHT. — COLORS OF BODIES.

420. Solar Spectrum. — If a beam of sunlight pass through a prism, it is bent from its course and at the same time is spread out into a brilliantly colored band called the *solar spectrum.* The spreading of the rays is called *dispersion;* it is caused by unequal refrangibility of the different colored rays. The angular dispersion of rays is different for different media.

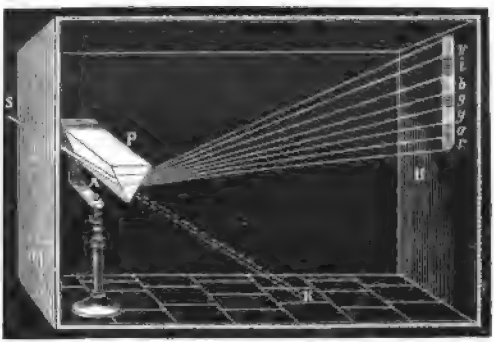

Fig. 283.

The method of forming a spectrum is shown in Fig. 283. The beam of light that enters a hole in the shutter of a darkened room falls on a prism whose refracting edge is turned downward; the whole beam is bent upward, and at the same time its elements are dispersed so as to form the elongated spectrum seen on the screen.

When a liquid is used it is enclosed in a hollow glass prism.

If the beam of light were unobstructed in its course, it would fall upon the floor at K, forming a circular spot of white light. In order to have the colors distinct, the opening through which the light enters should be very narrow. The refracting angle of the prism is usually 60°.

This spectrum consists of almost an infinite number of rays of different tints, but it is customary to consider only seven, and these are called *primary* colors. These, in the order of least refrangibility, are as follows: *red*, at r; *orange*, at o; *yellow*, at y; *green*, at g; *blue*, at b; *indigo*, at i; and *violet*, at v.

If a colored ray of the spectrum pass through a hole in a screen, and then fall on a second prism, it is deviated as before, but there is no further change of color; hence the colors of the spectrum are said to be *simple*.

The wave-lengths corresponding to different colored rays have been measured, and it is found that for red rays they are about $\frac{1}{39000}$ of an inch each, and for violet rays no more than $\frac{1}{57500}$ of an inch. The ether waves, then, gradually diminish in length from the red to the violet. The phenomena of dispersion indicate that shorter waves are more retarded than longer ones in passing through a medium; hence the rays at the red end of the spectrum are *least* refracted, and those at the violet end are *most* refracted.

Color in light corresponds to *pitch* in sound. The colors near the red end of the spectrum correspond to the graver sounds, and those near the violet end to the more acute sounds. The waves of the extreme violet end of the spectrum strike the retina with double the rapidity of the red. While, therefore, the range of audible sounds is nearly *eleven* octaves, the range of visible colors is scarcely *one* octave.

421. Recomposition of Light. — That white solar light is composed of rays of different colors can be proved in another way. When we recombine the colors of the spectrum white light will be reproduced. This can be done in several ways.

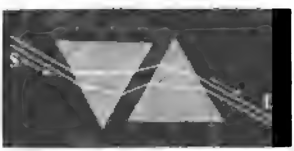

Fig. 284.

1. If it be acted on by a second prism exactly like the first, with its refracting edge

turned in the opposite direction, it will be recomposed and will emerge as white light (Fig. 284).

This amounts to nothing more than passing light through a medium bounded by parallel plane faces.

2. If it be received on a double-convex lens, as shown in Fig. 285, it will be recomposed, and an image will be formed free from color.

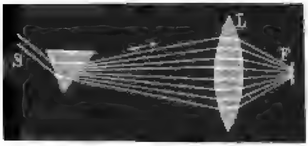

Fig. 285.

3. If the decomposed light be received upon a concave mirror (Fig. 286), it will in like manner be recomposed and a colorless image produced.

4. If a circular disk of cardboard be painted as shown in Fig. 287, in sectors, the colors being distributed according to intensity and tint, as in the spectrum, it will be found, on rotating the disk rapidly by a piece of mechanism shown in Fig. 287, that the separate colors blend into a single one, which is a grayish white.

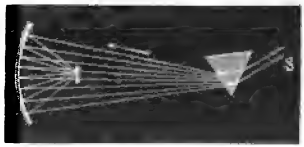

Fig. 286.

The color from any sector produces upon the eye an impression that lasts for an appreciable length of time. In the experiment the rotation is so rapid that the impressions from all the colors coexist at the same instant, and the effect is the same as though the colors were mixed.

That the impression produced by light lasts for an appreciable length of time may be shown by whirling a lighted stick round in a circle; it will present the appearance of a continuous circle of fire.

422. Color of Bodies. — The natural color of bodies is due to the fact that some of the colored rays in white light are absorbed when the light enters them. If the unabsorbed portion is transmitted, the body is colored and transparent;

if reflected, it is colored and opaque. In both cases the light that is not absorbed gives the color.

If a body absorbs all the colors, it is black; if it reflects or transmits all, it is white or colorless. A body appears red when it absorbs all the colors except the red, yellow when it absorbs all but the yellow, etc.

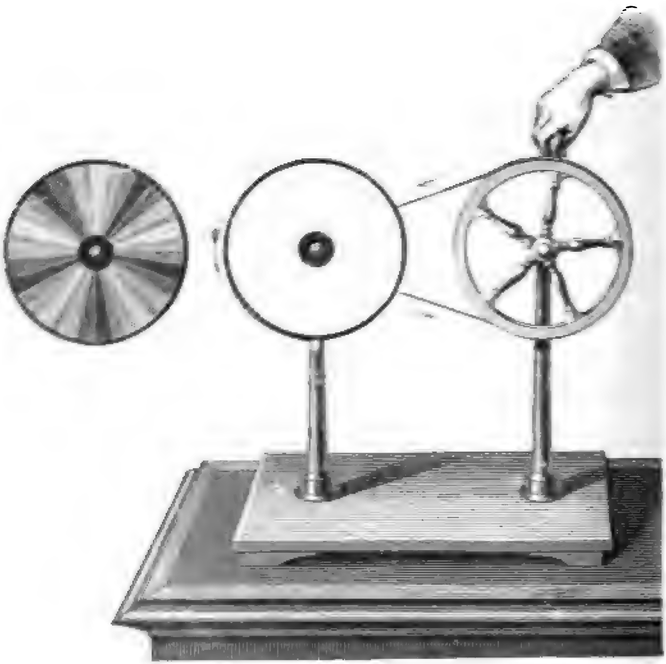

Fig. 287.

Water when seen in masses by transmitted light appears of a greenish hue. Air appears blue; hence the color of the sky. As we ascend, the mass above us becomes smaller and loses its blue tint. It is probable that the bluish tint of the heavens is also in a measure due to *reflection* from the aerial molecules. At sunrise and sunset, the rays of the sun have to traverse a great body of the atmosphere, which absorbs most of the rays except the red ones. Hence it is that the sun appears red at sunrise and sunset.

Some bodies transmit a color different from that which they reflect. Thus, gold appears yellow by reflected light and green by light transmitted through the leaf.

423. Complementary Colors.—NEWTON calls two colors *complementary* when by their mixture they produce white.

If all the rays of the spectrum except the red ones be recomposed by a convex lens, a greenish blue color will result; hence red and greenish blue are complementary. In like manner it may be shown that Prussian blue and orange are complementary, as are also violet and greenish yellow, and yellow and indigo blue.

424. Subjective Colors.—If a wafer upon a black ground be viewed intently for some time, until the nerve of the eye becomes fatigued, and the eye be then directed to a sheet of white paper, an image of the wafer will be seen upon the paper, whose color is complementary to that of the wafer. Thus, if the wafer is red, the image will be green; if the wafer is orange, the image will be blue; and so on.

If the setting sun, which is red, be viewed for some time, and then the eyes be directed to a white wall, a green image of the sun will be seen, which will last for some moments, when a red image will appear; a second green image succeeds it, and so on till the effect entirely ceases.

If we look for some time at a colored object on a white ground, we shall finally observe the object surrounded by a fringe, whose color is complementary to that of the body; thus, if a red wafer be placed upon a sheet of white paper, the fringe will be green.

Shadows cast upon a wall by the rising or setting sun are tinged green, the tint of the sun being red at that time.

If we examine several pieces of cloth of the same color, the eye becomes wearied, and in consequence of the accidental complementary color being formed, the last pieces examined appear of a different shade from those first viewed.

Tyndall explains these phenomena as follows: the eye, by looking at one color, the red wafer for instance, for some time, is rendered less

sensitive to that color, in fact partially blinded to its perception; hence, when the wafer is removed, the white light, falling upon the spot of the retina on which the image of the wafer rested, will have its red constituent virtually removed, and will therefore appear of the complementary color. Colors of this kind are called ***subjective colors***, since they depend upon the condition of the eye.

425. Fraunhofer's Lines.—The solar spectrum is not continuous; rays corresponding to certain degrees of refrangibility are wanting; hence it is crossed at intervals by dark lines. These are seen to best advantage in a spectrum formed by passing a beam of sunlight through a narrow slit, and then decomposing it by a prism whose

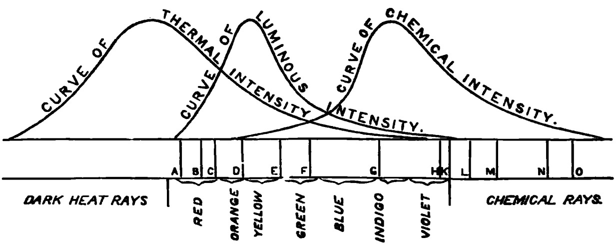

Fig. 288.

edges are parallel to the slit. The prism should be of flint glass and free from flaws. If the slit be wide the colors will overlap one another, but in a pure spectrum this must not be. A pure spectrum is obtained by making the slit very narrow.

The dark lines of the solar spectrum were noticed by WOLLASTON as early as 1802, but they were first studied and mapped by FRAUNHOFER in 1814; from that fact they have been called *Fraunhofer's lines.*

FRAUNHOFER'S chart contains between five and six hundred lines irregularly distributed. In it the most prominent lines are designated by letters, and these serve as points of comparison to which others may be referred. The line marked *A* (Fig. 288) is at the beginning, and *B* is near the middle of the red space; *C* is a well-marked line near the boundary of the red and orange; *D* is found in the orange;

E, in the yellow; and *F*, *G*, and *H* are well-marked lines, *F* being in the green, *G* in the indigo, and *H* in the violet.

FRAUNHOFER counted *nine* lines between *B* and *C*; *thirty* between *C* and *D*, *eighty-four* between *D* and *E*, *seventy-five* between *E* and *F*, *one hundred and eighty-five* between *F* and *G*, and *one hundred and ninety* between *G* and *H*. Recent observations have increased the number of dark lines till they are now counted by thousands.

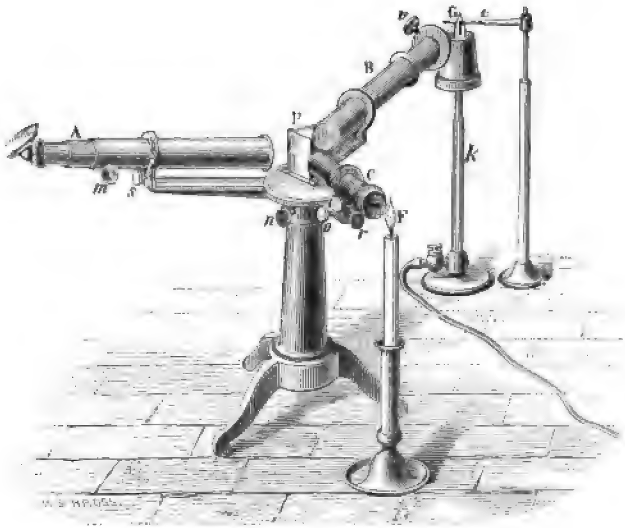

Fig. 289.

FRAUNHOFER found the spectra of the fixed stars to be crossed by dark lines, but the lines are differently arranged in the different stars, and in none are they arranged as in the solar spectrum. The spectra of the moon and planets whose light is reflected from the sun give the same lines as those of the sun. Recently the range of observation has been vastly increased, and on the results of these examinations a new branch of science has been founded, called *spectrum analysis*.

426. The Spectroscope.— The instrument used for forming and examining the spectra of bodies is called a *spectroscope*

(Fig. 289). It usually consists of three parts: a *collimator*, B; a prism, P, or a *train of prisms;* and a *telescope*, A.

The *collimator* is used to form a thin beam of parallel rays, coming from the flame, G, of a Bunsen burner, and consists of a narrow slit and a double-convex lens; the slit is formed by two jaws of metal that can be moved to and from each other, so as to give as narrow an opening as may be desired; the lens is behind the slit, and at a distance from it equal to its principal focal distance; hence it renders the rays that pass through it parallel to each other. The *train of prisms* serves to disperse the light; it consists of any number of prisms, having their edges parallel to the slit, and so placed that the light shall pass through them all in succession. The *telescope* is used to view the spectrum formed.

The tube, C, contains a graduated scale, an image of which is thrown upon the prism and reflected into the telescope when a light is placed in front of the tube. The observer can thus measure the relative distances of the lines of the spectrum.

The substance whose spectrum we wish to examine is volatilized in the flame at G. Instead of the flame of the burner we can make use of a beam of light reflected from the heliostat.

427. Spectrum Analysis. — Explanation of Fraunhofer's Lines. — Metals and their compounds impart characteristic colors to flames: thus, sodium and its compounds impart a yellow color to a Bunsen burner; the compounds of copper render it green, the compounds of zinc make it purple, and the compounds of strontian give it a red color. These colors are due to the *vapors* of the corresponding substances, and are peculiar to those vapors. If these or any other incandescent vapors be examined with the spectroscope, their spectra are found to consist of bright bands, each corresponding to a definite degree of refrangibility. The number, color, and position of the bands in every case are perfectly characteristic, and always serve to identify the body producing the spectrum. This mode of determining the presence of bodies is called *spectrum analysis*.

If two or more metals be vaporized in the flame at the same time, the bands peculiar to each are formed as though the others did not

exist. If a mineral substance containing many different metals be volatilized, the spectrum will show the bands characteristic of each. Bunsen and Kirchoff discovered the new metals Rubidium and Cæsium, by means of bands shown by the spectroscope, which differed from those of all the metals previously known; and in like manner Mr. Crookes discovered the new metal Thallium.

The method of spectrum analysis is exceedingly delicate; the presence of the minutest portion of any substance in the form of incandescent vapor is instantly made manifest by its characteristic lines in the spectrum.

It has been shown that an incandescent solid or liquid gives a continuous spectrum. If light from such a source be transmitted through the vapors of any substances, and then examined with the spectroscope, the resulting spectrum will be crossed by dark lines having the same position as the bright lines belonging to the spectra of the vapors. Hence it appears that every body in a state of vapor is opaque to the class of rays that it emits when rendered incandescent.

The principle just elucidated has been applied to explain the dark lines of the solar spectrum. It is supposed that the body of the sun is an incandescent solid, or perhaps a glowing liquid, and consequently that it emits white light. It is further supposed that the body of the sun is surrounded by a layer of gaseous matter containing vapors of various substances, including many of the known metals. This envelope, called the photosphere, being at a lower temperature than the nucleus, is in a condition to absorb the very rays that it would itself emit if it were incandescent. The absorbed or missing rays form the dark lines of the spectrum. Were the central nucleus abolished, the solar spectrum would be transformed into a system of brilliant bands. These would correspond to the bands of a spectrum given by a flame charged by metallic vapors. They would constitute the spectrum of the solar photosphere.

Sodium, *calcium*, *magnesium*, *iron*, *chromium*, *nickel*, *copper*, *zinc*, and other metals have been found in the solar atmosphere.

The spectra of the fixed stars indicate that those bodies are similar in constitution to our sun, but the number and position of the dark lines show that their photospheres do not contain the same elements that are found in our own luminary.

The nebulæ, where they can be observed, give out spectra like ignited gases instead of spectra like the sun and stars.

The *permanent gases*, when heated to a sufficient temperature by means of electricity, exhibit bands in their spectra.

It has long been known that the sun is surrounded during the time of a total eclipse by a great number of irregular rose-colored protuberances. These have been shown by spectrum analysis to consist, for the most part, of incandescent hydrogen; with it are mixed vapors of sodium and magnesium. The protuberances form part of an irregular envelope surrounding the entire body of the sun, and lying outside of its photosphere. This layer constitutes what has been named the chromosphere, and within a few years a method has been discovered for observing its spectrum without the necessity of waiting for a total eclipse.

428. Interference of Light. — If two waves of light move in such a way that the crest of one coincides with the crest of the other, and the depression of one with the depression of the other, the resultant will be a wave of double amplitude of vibration.

But when the crest of one corresponds to the depression of the other, they neutralize each other and there is no light.

429. Newton's Rings are explained on the same principle. Upon a flat, smooth piece of glass let the convex side of a plano-convex lens having a small curvature be placed and firmly pressed down, as shown in Fig. 290. Suppose a beam of homogeneous light, that is, light of one color, is allowed to fall perpendicularly upon the upper glass; a portion will be reflected from the lower surface of the lens and a portion from the upper surface of the lower glass.


Fig. 290.

The centre, which is the point of contact of the two glass surfaces, is a dark circular spot; at a certain distance from it, the two sets of reflected waves, as they go together to the eye, will have the crest of one coinciding with the depression of another, and the effect will be darkness, or there will be a black ring formed. A little farther out, the crests will coincide, and we shall have a bright ring of the same

color as the beam of light. Farther still from the centre the crests and depressions will again correspond, and we shall have a dark ring, and so on.

The appearance presented to the eye will be a series of rings, dark and bright alternately, as represented in Fig. 291. If yellow light be used, we shall have alternately dark and yellow rings; if red light, dark and red rings; and other colors will produce similar results.

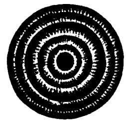

Fig. 291.

If a beam of solar light is used, each ring will take the colors of the spectrum, — violet on the inner edge, and red on the outer, in order of their refrangibilities.

By finding the thickness of the layer of air between the two glasses, the wave-lengths have been determined.

The colors of finely grooved surfaces are due to interference. These colors are independent of the physical constitution of the body, and depend solely on the fineness and shape of the grooves.

The play of colors upon mother-of-pearl is due to fine grooves or striæ, as may be shown by taking an impression of a piece of it in white wax; the colors of the wax, thus prepared, are entirely analogous with those of the mother-of-pearl from which the impression was taken.

The brilliant colors of a soap-bubble are due to the interference of the two sets of rays that are reflected from the outer and inner surfaces of the film that constitutes the bubble.

The colors of thin plates, like the film of oil on water, the splendid colors of the skimmings of melted lead, the iridescent displays of fractured crystals, and the like, are all due to interference of light.

430. Diffraction. — When light passes the edges of opaque bodies, the luminous rays appear to become bent and to enter the shadow of the body.

If a ray of light pass by a very small aperture into a darkened room, and an opaque body be placed in it, the shadow that it casts will be surrounded with colored fringes.

If the body be a hair or fine metallic wire, there will not only be exterior fringes, but also a series of dark and colored bands in the shadow itself, which are called interior fringes. These phenomena are due to the interference of light.

Summary. —

Solar Spectrum.

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Wave-Lengths and Color.

Recomposition of Light.

1. By two Prisms.
2. By Double-Convex Lens.
3. By Concave Mirror.
4. By Revolutions of Cardboard.

Color of Bodies.

Explanations of the Natural Color of Bodies.

Examples to illustrate Color.

Bodies that transmit Color different from that which they reflect.

Complementary Colors.

Definition and Manner of Production.

Subjective Colors.

Examples.

Explanation of Tyndall.

Fraunhofer's Lines.

Method of producing these Lines.

Illustration by Figure.

The Spectroscope.

Description and Illustration by Figure.

Spectrum Analysis.

Characteristic Flames of different Metals and their Compounds.

Colored Flames due to their Vapors.

New Metals discovered by the Spectrum.

Bodies Opaque to Rays they emit when Incandescent.

Constitution of the Heavenly Bodies indicated by their Spectra.

Interference of Light.

Explanations.

Newton's Rings explained by Figures.

Examples of Interference of Light.

Explanation of Diffraction of Light.

431. Double Refraction. — Certain crystalline substances have the power of separating a transmitted beam into two parts, so that objects seen through them appear double, as shown in Fig. 292. This phenomenon, called *double refraction*, depends on the molecular arrangement of the body, which causes the contained ether to have different degrees of elasticity in different directions.

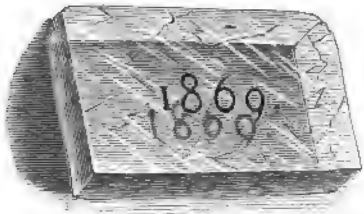

Fig. 292.

Iceland spar, which is crystallized carbonate of lime, is an example of double refracting bodies. Its crystals can be reduced by cleavage to the form of an equilateral rhomb, as shown in the figure. The particles are symmetrically arranged about the shortest diagonal (*a b*, Fig. 293), and this is called the axis. On account of the inequality in the arrangement of the molecules, the surrounding ether is endowed with different degrees of elasticity. In consequence of these unequal elasticities, the transmitted wave is divided into two, which advance with unequal velocities; hence the phenomena of double refraction. Where the elasticity is the greatest, the velocity is the greatest and the refraction the least, and the reverse also is true.

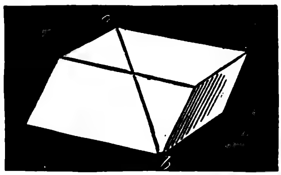

Fig. 293.

The two parts into which a ray is divided do not move according to the same law. One follows both the laws of refraction already explained; it is called the *ordinary ray*. The other does not, as a general thing, follow either of those laws; it is called the *extraordinary ray*. When transmission takes place in the direction of the axis the two rays coincide, and this direction of *no-double* refraction is called the *optic axis* of the crystal; when in a plane perpendicular to the axis, the two rays are most separated. If we turn the spar round (Fig. 293), the image made by the extraordinary ray will revolve about the other, while that remains stationary.

The class of bodies to which Iceland spar belongs have but one optic axis; these are called *uniaxial*. There are bodies that have two optic axes; these are called *biaxial*.

In all crystals where the molecules are not grouped alike, the elasticity of the ether is not the same, and double refraction occurs. Ice will cause double refraction, but water will not, thus showing a difference of molecular arrangement.

432. Polarization of Light. — If a beam of light be transmitted through a crystal of Iceland spar, the parts into which it is divided are of equal intensity. If one of these parts be transmitted through a second crystal, the parts into which it is divided are of unequal intensity, and the degree of inequality depends on the relative positions of the crystals. Hence light that has been doubly refracted differs from common light; it is *polarized*, or, in other words, it has acquired *sides*.

The vibrations that constitute light are *transversal;* that is, they are perpendicular to the direction of propagation. In *common* light the vibrations (Fig. 294) take place in every possible direction consistent with this law; in *polarized* light they take place in only one direction, or are all in one plane, called the *plane of polarization.*

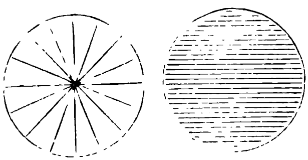

Fig. 294.

Certain crystals have the power of arranging these transverse vibrations of ordinary light into two sets at right angles to each other (Fig. 295).

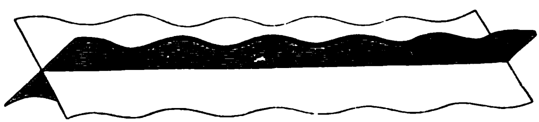

Fig. 295.

One of the sets is more retarded than the other in passing through the crystal, and is generally the *ordinary* ray, which has been described.

433. Polarized Light and Tourmaline. — Light is best studied by allowing it to fall perpendicularly on a plate of tourmaline, cut parallel to the axis of the crystal. Such a plate

allows no vibrations to pass except they be parallel to the axis. Hence the emergent beam is polarized. Let such a beam fall perpendicularly on a second plate, similar to the first. If the axes of these plates are parallel (Fig. 296), the entire beam is wholly transmitted; if the axes are perpendicular to each other, the beam is wholly intercepted; if the axes are oblique to each other, the beam is partially transmitted and partially intercepted.

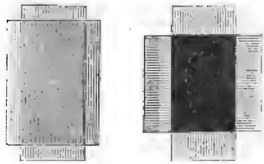

Fig. 296.

This can be further illustrated by Fig. 297. *A* and *C* represent two gratings with parallel bars, corresponding to the plates of tourmaline. *B* is a cardboard corresponding to the transverse vibrations of a light-wave.

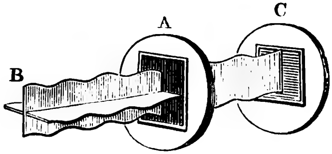

Fig. 297.

It can be readily seen that the vertical portion passes through the bars at *A*. This is the polarized ray, the vibrations being all in one plane. It is evident also that it cannot pass through the bars at *C* in their present position.

That which polarizes light is called a *polarizer*, and whatever is used to examine polarized light is called an *analyzer*. Of the two tourmaline plates mentioned, the first is a polarizer, the second an analyzer. To test whether light is polarized, it is usual to observe it through an analyzer, and to notice whether there be any change of brightness as the analyzer is rotated.

If the rays that have passed through a crystal of Iceland spar be tested by a plate of tourmaline, it is found that they are polarized in planes which are perpendicular to each other.

Light may be polarized by reflection and refraction. We have seen, when a ray of light, *A C*, falls on a surface separating two media (Fig. 298), that it is separated into two parts, one of which,

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ıys from each drop that do not reach the eye are figure.

cupies a position on a line which, if produced, passes an and the centre of the rainbow circle.

ıys of the primary bow as they emerge from the drops le with the sun's rays of 42°, the blue rays 40°, and the between these. The different colors will be seen in arcs of circles, the emergent rays making the constant angles just

gles which the rays of the secondary make are larger than ıe primary.

sun goes towards the horizon the bow rises; when it is in on it forms a semicircle.

sun is below the horizon and the observer on an elevation, ole bow may be seen.

primary bow disappears if the sun is more than 42° above the n; the secondary, if more than 54°.

nce the position of the rainbow depends upon the direcof the sun's rays and the position of the observer, no persons see precisely the same bow, although, if they near together, the bows very nearly coincide.

The rainbows of any two successive moments are not the me, for the drops that form them are constantly succeeding ıe another in rapid succession.

We often see the colors of the rainbow in the dewdrop, in icicles, in the ice that often clothes the twigs and branches of trees in winter. The entire circle of rainbows may be seen in the spray that arises from cataracts. The halos often seen around the moon and sometimes around the sun are supposed to be due to reflections and refractions of the light.

438. **The Properties of the Spectrum.**—The seven rays enumerated differ in illuminating power, the middle rays being those which possess the greatest illuminating power; that is, the most powerfully illuminating rays lie midway between the heat rays and the actinic rays, namely, in the yellow.

If a thermometer be held for a time in the different rays,

suffer two refractions and one reflection; hence not so much light is lost, and the bow is brighter. The result is, that the emergent light is resolved into the seven prismatic colors for each bow, only those of the secondary are in the reverse order of the primary on account of the additional reflection.

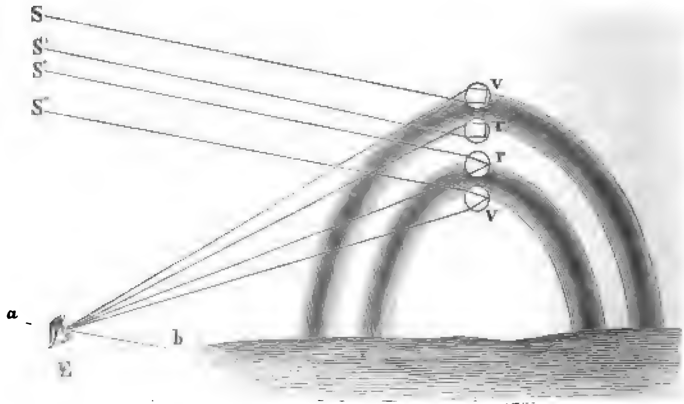

Fig. 302.

In the primary bow, violet occupies the inside, red the outside; in the secondary, violet the outside and red the inside, the intermediate colors taking their proper order.

437. **The Manner** in which the rays come to the eye from the seven drops to form the primary bow is shown in Fig. 303.

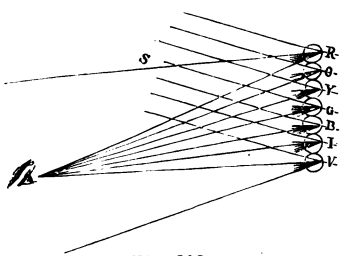

Fig. 303.

The secondary is formed in a similar way except that the eye catches the red ray from the first drop and violet from the seventh, the intermediate drops furnishing their respective rays. Of course the seven drops of the secondary bow are above the seven of the primary.

The colored rays from each drop that do not reach the eye are shown in the figure.

The eye occupies a position on a line which, if produced, passes through the sun and the centre of the rainbow circle.

The red rays of the primary bow as they emerge from the drops make an angle with the sun's rays of 42°, the blue rays 40°, and the other colors between these. The different colors will be seen in arcs of concentric circles, the emergent rays making the constant angles just given.

The angles which the rays of the secondary make are larger than those of the primary.

As the sun goes towards the horizon the bow rises; when it is in the horizon it forms a semicircle.

If the sun is below the horizon and the observer on an elevation, the whole bow may be seen.

The primary bow disappears if the sun is more than 42° above the horizon; the secondary, if more than 54°.

Since the position of the rainbow depends upon the direction of the sun's rays and the position of the observer, no two persons see precisely the same bow, although, if they are near together, the bows very nearly coincide.

The rainbows of any two successive moments are not the same, for the drops that form them are constantly succeeding one another in rapid succession.

We often see the colors of the rainbow in the dewdrop, in icicles, in the ice that often clothes the twigs and branches of trees in winter. The entire circle of rainbows may be seen in the spray that arises from cataracts. The halos often seen around the moon and sometimes around the sun are supposed to be due to reflections and refractions of the light.

438. **The Properties of the Spectrum.** — The seven rays enumerated differ in illuminating power, the middle rays being those which possess the greatest illuminating power; that is, the most powerfully illuminating rays lie midway between the heat rays and the actinic rays, namely, in the yellow.

If a thermometer be held for a time in the different rays,

beginning at the violet, it will show an increase of heat till it comes outside of the red rays, where it is greatest.

The actinic rays are those that produce chemical changes. If a strip of paper, prepared with nitrate of silver, be placed in the spectrum, it will be least changed in the red, and in passing towards the violet end this change will increase till it becomes the greatest beyond the violet.

In Fig. 288 we have represented by means of curves the relative intensities of the three properties of the spectrum.

The rays below the red of the spectrum, or ultra-red rays, and those above the violet, or ultra-violet rays, are called *invisible rays*, to distinguish them from the colored portions of the spectrum, which are called the *visible rays*. Strictly speaking, however, no rays are visible or invisible; it is not the rays that are seen, but the objects they illuminate.

439. Fluorescence and Calorescence. — If the ultra-violet rays are permitted to fall upon certain substances, as sulphate of quinine, for example, or common paraffine oil, their refrangibility is lowered and they become luminous. This change is called *fluorescence*, the name having been originally suggested by a variety of fluor spar which produces the effect.

Tyndall has succeeded in raising the refrangibility of the ultra-red rays and in making them visible. He brought the rays of the electric lamp to a focus by means of a reflector, and then stopped the luminous rays by interposing a vessel of rock-salt containing a solution of iodine. He found that a piece of platinum foil when brought into the focus was heated to incandescence, and thus emitted light as well as heat. This transformation of dark heat-rays to light he called *calorescence*. Sunlight will produce similar effects, but the results are not so marked.

440. Chromatic Aberration. — The light that falls on a lens is decomposed into colored rays of different degrees of refrangibility. These rays are brought to different foci along the axis, giving rise to a multitude of partial images

of different colors, which by superposition produce a single image slightly indistinct, and fringed with all the colors of the spectrum. This scattering of the colored rays to different foci is called *chromatic aberration.*

Fig. 304 shows the phenomenon of chromatic aberration. The red rays, being less deviated than the others, are brought to a focus beyond them at *r*, while the violet rays, being more refrangible than the others, are brought to a focus within them at *v*. Between *v* and *r* the intermediate colors are also brought to foci.

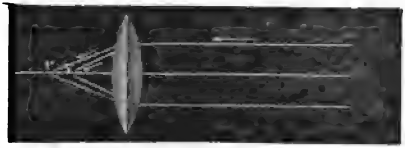

Fig. 304.

441. Achromatic Combinations. — An ACHROMATIC COMBINATION consists of two or more lenses of different kinds of glass, so constructed as to neutralize the effect of dispersion.

The combination usually consists of two lenses: a convex lens made of crown glass, and a concave lens made of flint glass, as shown in Fig. 305. Flint glass disperses light more than crown glass. The combination, having its thickest part at the middle, is convergent. The dispersion of the rays by one of the lenses is exactly neutralized by a dispersion of them in an opposite way, so that the image is nearly colorless.

Fig. 305

Such combinations of lenses are called *achromatic*, and are the ones used in the construction of telescopes.

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Double Refraction.

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Ordinary and Extraordinary Rays.

Polarization of Light.

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Vibrations of Common and Polarized Light shown by Figure.

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Polarized Light and Tourmaline.

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The Tourmaline Pincette.

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In determining the Light of the Heavenly Bodies.

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Primary and Secondary Bows explained by Figure.

The Manner in which the Rays reach the Eye explained by Figure.

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No two Persons see the same Bow.

Rainbow Colors seen in Dewdrops, Icicles, etc.

Properties of the Spectrum.

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Positions determined in the Spectrum.

Relative Intensities illustrated by Figure.

Fluorescence and Calorescence.

Explanations by Experiments.

Chromatic Aberration explained by Figure.

Achromatic Combinations explained by Figure.

SECTION V.—THEORY AND CONSTRUCTION OF OPTICAL INSTRUMENTS.

442. Optical Instruments. — The properties of mirrors and lenses have led to the construction of a great variety of instruments, which, by increasing the limits of vision, have opened to our senses two new worlds that had else remained unknown to us, the one on account of its minuteness and the other on account of its immensity.

Of the optical instruments, the most useful and interesting are *microscopes* and *telescopes*.

Besides these a great variety of other instruments have been devised, such as the *magic lantern*, the *photo-electric microscope*, the *solar microscope*, the *camera obscura*, and the *stereoscope*.

443. Microscopes. — A MICROSCOPE is used for viewing near objects.

Microscopes may consist of a single lens or a combination of lenses. We shall describe the two kinds, the *simple* and the *compound*.

444. The Simple Microscope, or magnifying-glass, consists of a double-convex lens of short focal distance. It is usually set in a frame of metal or of horn, and held in the hand.

The object is placed between the lens and its principal focus. The image is erect, virtual, and magnified (Fig. 278). The visual angle subtended by the image is greater than that subtended by the object; hence the enlargement of the image.

445. The Compound Microscope consists essentially of a double-convex lens called the *object-lens*, and a second double-convex lens called the *eye-piece*.

Fig. 306 shows the instrument in section, and makes known the course of the rays.

The object to be observed is placed at a, between two plates of glass upon a support. o is the object-lens, and O the eye-piece. The object, a, being placed a little beyond the

principal focus of the object-glass, this lens produces a real image, *b c*, which is inverted and enlarged. The eye-piece, *O*, is so placed that its principal focus is a little beyond the image, *b c*. This lens then acts as a simple microscope, and magnifies the image as though it were at *BC*.

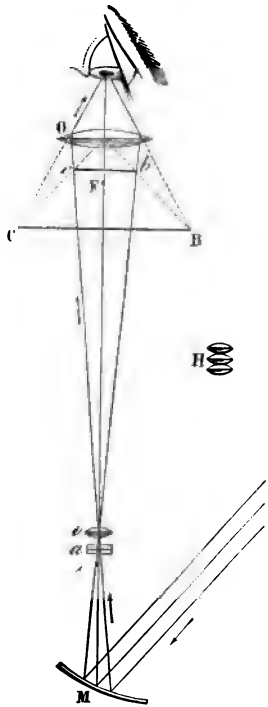

Fig. 306.

The compound microscope excels the simple in magnifying power because with it we examine not the object itself but an enlarged image of it. The magnifying power of a microscope is generally expressed in *diameters*. If it makes the breadth of the object appear 100 times as great as it really is, it is said to magnify 100 diameters, the surface being magnified $100^2 = 10,000$ times.

Compound microscopes are constructed whose magnifying power is 1,800 diameters; but what is gained in power is often lost in distinctness. A good magnifying power is 600 diameters, which gives 360,000 in surface.

The magnifying power depends upon the object-lens. This power is increased by combining two or three lenses, as shown at *H*, on the right of Fig. 306. The eye-piece and object-glass often consist of two or more lenses, acting, however, as a single lens, for the purpose of remedying the defect arising from spherical and chromatic aberrations.

The magnifying power of the compound microscope is equal to the magnifying powers of the two glasses.

As there is no more light on the magnified image than on the object itself, the object must be strongly illuminated, so that the diffused light may be sufficient to meet the eye. To secure this, the object, when transparent, is illuminated by a mirror, *M* (Fig. 306), which

concentrates the light upon it. When the object is opaque, it can be illuminated by a lens, which concentrates the rays upon it from above.

The microscope is used in the study of botany to discover the laws of the vegetable world; in entomology, to study the habits of minute insects; in anatomy and medicine, to study the laws of animal physiology; in the arts, to discover the composition of mixtures; in commerce, to detect the nature of stuffs; and so on. Its use is almost universal, either as an instrument of research or of curiosity.

446. Telescopes. — A TELESCOPE is an optical instrument for viewing objects at a distance.

Telescopes may be divided into two classes, *refracting* telescopes and *reflecting* telescopes.

In the first class a lens, called the *object-lens*, is employed to form an image; in the second class a mirror or speculum is employed for the same purpose; in both, the image formed is viewed by a lens, or combination of lenses, called the eye-piece. The manner of arranging these component parts, together with the nature of the auxiliary pieces employed, determines the particular kind of telescope. We will first consider the refracting telescopes.

447. The Galilean Telescope, named from its illustrious discoverer, GALILEO, consists essentially of a *convex object-glass*, which collects the rays from an object, and a *concave eye-piece*, by means of which the rays from each point of the object are rendered parallel, and capable of producing distinct vision.

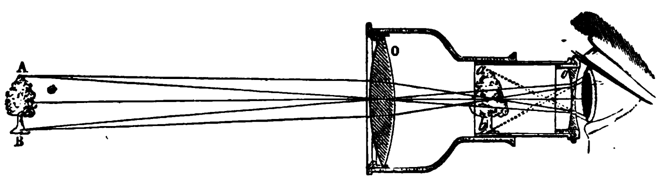

Fig. 307.

Fig. 307 shows the course of the rays in the Galilean telescope. Pencils of rays from points of the object, *A B*, falling upon the object-lens, *O*, are converged by it, and tend to

form a real and inverted image beyond the eye-piece, *o*. The concave eye-piece is placed so as to intercept the rays coming from the object-glass, being at a distance in front of the inverted image equal to its own principal focal distance. In consequence of this arrangement, the pencil of light coming from *A* is converged by the object-glass, and, falling upon the eye-piece, is diverged and refracted so as to appear to the eye to come from *a*. In like manner the pencil from *B* appears to the eye to come from *b*.

The image is erect and virtual, and because the visual angle (Art. 376) under which the image is seen is greater than that under which the object would be seen without the telescope, it appears magnified.

Opera-glasses are simply Galilean telescopes. The length of this telescope is equal to the difference of the focal lengths of the two glasses, and therefore has the advantage of being short and portable.

448. **The Astronomical Telescope** consists essentially of two convex lenses, the one, *o*, being the object-lens, and the other, *O*, the eye-piece. The object-glass forms an inverted image of the object, which is viewed by the eye-piece.

Fig. 308 represents the course of the rays in this instrument. A pencil of rays coming from *A* is converged by *o* to a focus, *a*, while a pencil from *B* is brought to the focus, *b*. In this manner the lens, *o*, forms an image, *a b*, of an object,

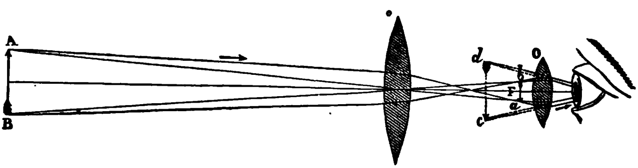

Fig. 308.

A B, which image is real and inverted. The eye-piece, *O*, is placed at a distance from *a b* a little less than its principal focal distance. The pencil coming from the points *a* and *b* of the image are refracted so as to appear to come from the points

c and *d*. The visual angle is greater than it would be in viewing the object without the telescope, and consequently the object appears to be magnified.

In this, as in all other telescopes, the eye-piece is capable of being pushed in or drawn out, to enable the observer to accommodate it to near as well as distant objects.

The object-glass is made as large as practicable, to illuminate the image as much as possible, and should be achromatic (Art. 441).

The size of the image increases with its distance from the object-glass; it should therefore be of small convexity, that its focal distance may be as great as possible. The eye-piece should have great convexity, and consequently short focal length, as it does the magnifying.

To find the magnifying power of a telescope, we divide the focal length of the object-glass by that of the eye-glass.

This telescope differs from the microscope in these respects; the object-glass of the latter is as small as possible, very convex, and also has the object to be examined very near it, so that the image formed is much beyond the principal focus, and greatly magnified. Consequently both object-glass and eye-glass magnify. Whereas, in the telescope, the heavenly bodies being at an immense distance, the incident rays are parallel, and the image formed in the principal focus of the object-glass is smaller than the object itself. The object-glass also, as has been stated, is as large as possible, has very little convexity, and does no magnifying, the eye-piece doing that.

The length of the astronomical telescope equals the *sum* of the focal lengths of the two glasses.

449. **The Terrestrial Telescope** differs from the astronomical telescope in having two additional lenses, which

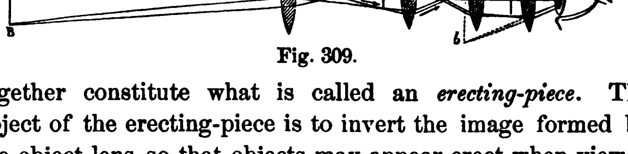

Fig. 309.

together constitute what is called an *erecting-piece*. The object of the erecting-piece is to invert the image formed by the object-lens, so that objects may appear erect when viewed through the telescope.

Fig. 309 shows the course of the rays in a terrestrial telescope. $A B$ is the *object*, o is the *object-lens*, m and n, two convex lenses, constitute the erecting-piece, and O is the *eye-piece*.

The erecting-piece is so placed that the distance of the image, I, shall be at a distance from m equal to its principal focal distance.

A pencil of rays from A, falling upon the object-lens, is converged to a focus at the lower end of the image, I; the pencil proceeding from I is converted into a beam by the lens, m, directed obliquely upwards, which beam is converged to a focus at i. In this manner an erect image, i, is formed, which is then viewed by the eye-piece, O. The eye-piece refracts the pencils coming from the image, i, so as to make them appear to come from $a b$.

The angle under which $a b$ is seen is the *visual angle*, and, being greater than the angle under which $A B$ would be seen without the telescope, the object is magnified.

The magnifying power is the same as in the astronomical telescope provided the correcting glasses, m and n, have the same convexity; the loss of light, however, is greater.

The terrestrial telescope is used at sea and on land for viewing objects at a distance.

450. Reflecting Telescopes. — A REFLECTING TELESCOPE is one in which the image of a distant object is formed by means of a reflector or speculum, which image is then viewed by an eye-piece. The eye-piece is either a single lens or a combination of lenses.

One of the first telescopes of this description was constructed by NEWTON, and this is the only one of the kind which we shall describe in detail.

451. Newtonian Telescope. — Fig. 310 shows the telescope of NEWTON in section, and indicates the course of the rays of light.

M is a parabolic mirror placed at the bottom of a long

tube. This reflector tends to form a small image of an object at the other end of the tube. But before the rays reach the image they are intercepted by a prism of glass, *m n*, so arranged that the rays enter its first face without deviation, and strike its second face so as to be totally reflected, which causes the image to be formed at *a b*. The prism, *m n*, replaces the inclined mirror used in the old form of Newtonian telescope. The image thus formed is viewed by an eye-piece

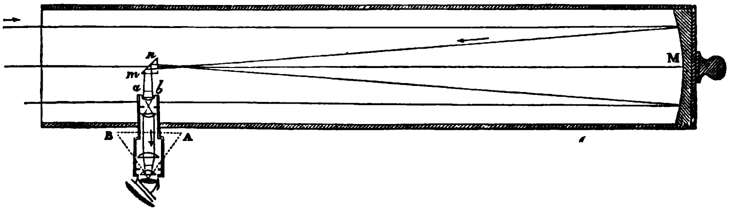

Fig. 310.

through the side of the telescope. The eye-piece in this telescope is made of two plano-convex lenses, as shown in the figure, the combined effect of which is to cause the image to appear in the position *B A*, giving a great power to the telescope.

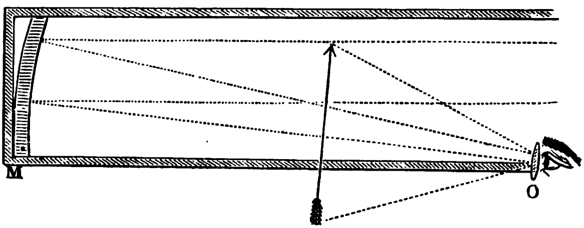

Fig. 311.

452. **Herschel's Telescope.** — Sir William Herschel, of London, modified the Newtonian telescope by inclining the mirror, *M*, so as to throw the image to one side of the tube (Fig. 311), where it could by viewed by a magnifying

eye-piece, the observer's back being turned towards the object.

The largest reflecting telescope ever made is that of Lord Rosse, which has a diameter of 6 feet and a focal length of 53 feet. It is at present used as a Newtonian telescope, but can be used like Herschel's.

453. **The Magic Lantern** is an apparatus for forming upon a screen enlarged images of objects painted on glass.

Fig. 312 represents a section of the lantern. It is composed of a box, in which a lamp is placed before a reflector, *M;* the light is reflected upon a lens, *L*, and is converged so as to illuminate strongly the plate of glass, *a b*, upon which the picture is painted. Finally, a combination of two lenses, *m*,

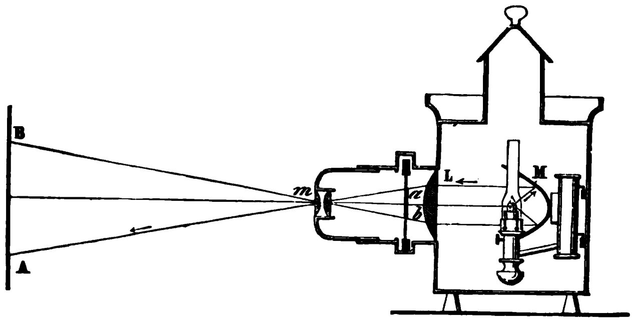

Fig. 312.

acting as a single-convex lens, is placed so that the plate, *a b*, shall be a little beyond its principal focus. At this distance the lenses produce (as shown in Fig. 277) a magnified and inverted image of the picture painted on the glass. The picture on the glass should be inverted, in order that its image may appear erect.

The image on the screen will be the more magnified as the plate, *a b*, approaches the principal focus of the compound lens, *m*. It will also be the more magnified as the compound lens increases in power.

The magnifying power of the lantern is found by dividing the

distance of the lens, *m*, from the image by its distance from the object.

454. The Polyrama and Dissolving Views. — The POLYRAMA consists of a double magic-lantern, with two cut-off screens. DISSOLVING VIEWS are obtained by using both lanterns. Thus, if a picture of a daylight scene be painted on one of the slides, and of the same scene by moonlight be painted on the other, the first picture is thrown upon the screen strongly illuminated, the other one being entirely excluded by a screen that cuts off the second lens. By an arrangement operated by the exhibitor, the light is gradually cut off from the first picture and admitted upon the second, the first fading away insensibly while the second as gradually grows brighter. In this way all the effects intermediate between full daylight and full moonlight may be obtained in succession.

A volcano, calm, and only surmounted by a light cloud of smoke, may be followed by a picture of the same volcano sending forth volumes of flame and smoke. A storm may be made to succeed a smiling landscape, and so on. The illusion is complete.

Since the brightness of the image diminishes as we enlarge it, our illuminating power must be very great. Instead, therefore, of oil lamps, the *magnesium*, *calcium*, and *electric* lights are used to intensify the light.

The *magnesium* light is made by burning a narrow ribbon of the metal; it gives a brilliant and dazzling light.

If a piece of unslaked lime is placed in a flame of mixed hydrogen and oxygen gases from a blow-pipe, a vivid light is the result; this is called the *calcium* light.

The *electric* light is the brightest of artificial lights, and is briefly described in the next article.

455. The Photo-Electric Microscope is constructed on the same optical principles as the magic lantern, except that the light employed is obtained by passing an electric current between two charcoal points.

Fig. 313 represents in detail the arrangement of this instru-

ment. At the foot of the apparatus is a battery for generating electricity, which will be described hereafter. The electricity is conveyed to the charcoal points in the box, *B*, by means of two copper wires, one going to the upper and the other to the lower point. The points being slightly separated, the circuit is completed only by the electricity passing

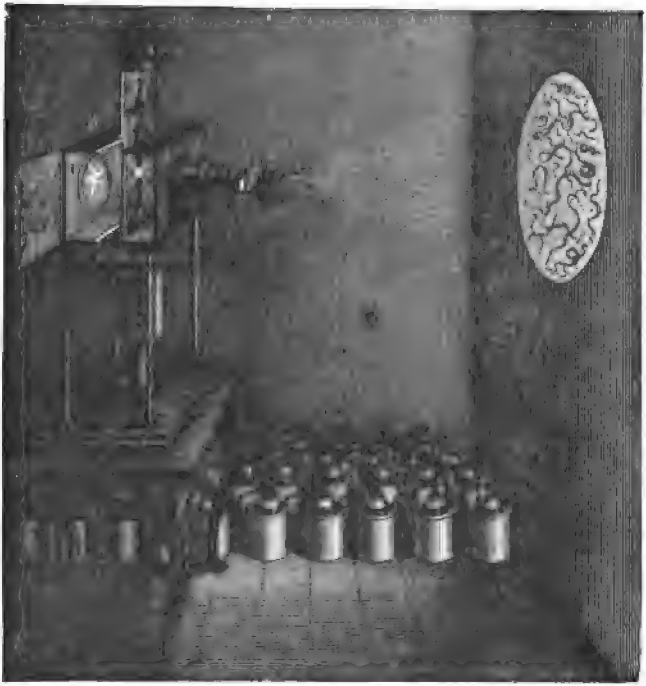

Fig. 313.

across the interval, which gives rise to a light of extreme brilliancy.

In the figure, *I* represents a parabolic reflector for concentrating the light upon the slide, *X*, through a lens, *C*. *D* is a lens which forms a magnified image of the minute object on a screen. The tube in which the lens, *D*, is placed may be

drawn out or pushed in to vary the magnifying power of the apparatus.

The magnifying power of this instrument may be made extremely great, and by suitable management it serves to show to a large company the wonders of the microscopic world. One of the most remarkable experiments made with it is to show the circulation of the blood. Instead of a picture on the slide, let the tail of a tadpole be placed between two plates of glass and introduced. There will appear upon the screen what seems an illuminated map, all of whose streams flow with a rapid current. It is but the blood circulating with great velocity through the arteries and veins.

The phenomena of crystallization are exceedingly beautiful when seen by this microscope. If a drop of a solution of sal ammoniac, for example, be poured upon a plate of glass, and then introduced into the instrument, the heat will cause the water to evaporate, producing one of the most beautiful examples of crystallization that can be exhibited. The minute animalcula of solutions and stagnant water can be shown by this microscope.

When the magnesium, calcium, or electric light is used, the lantern is called a *stereopticon.*

To the oil-lantern the names *magic lantern*, *lamposcope*, and *sciopticon* are given.

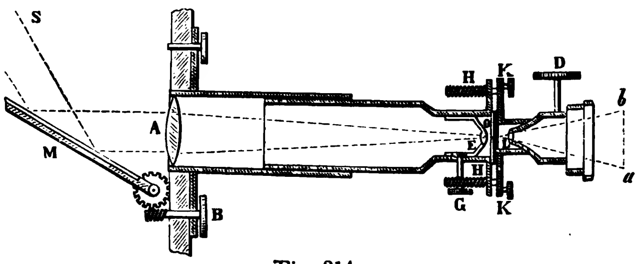

Fig. 314.

456. The Solar Microscope. — When the light of the sun is used instead of the electric light, the apparatus is called the *solar microscope*. *M* (Fig. 314) is an inclined mirror which throws the solar rays into the tube of the microscope through the lenses, *A* and *E*, which concentrate them upon the object, *O*. The lens, *L*, then brings them to a focus at *a b*.

The endless screw, *B*, gives the proper inclination to the mirror.

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Solar Microscope.

Construction and Method of using it explained by Figure.

457. **Camera Obscura.** — The camera obscura (dark chamber) is, as its name indicates, a closed space, as, for example, a room shut off from the light, with the exception of the luminous rays that are allowed to enter through a small aperture, as shown in Fig. 315.

The rays proceeding from external objects and entering through this aperture form on the side opposite the aperture an image of the object, inverted and diminished in size, but retaining the colors of the object. The inversion of the image is due to the crossing of the rays.

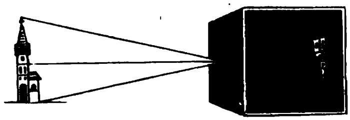

Fig. 315.

If the aperture is a large one, the rays are scattered indiscriminately over the whole picture, and the image is not so distinct as when the aperture is small. The image will be distorted if the screen is not perpendicular to the direction of the rays.

The images formed by a camera obscura possess the remarkable peculiarity of being entirely independent of the shape of the opening, in the box, provided it be quite small. The shape of the images is the same, whether the opening be square, round, triangular, or oblong.

To show this, let us consider the case of a beam of solar light entering a dark room through a hole in a shutter (Fig. 316). With respect to the sun, the hole in the shutter is but a point; hence the group of rays which enter it form in reality a cone whose base is the sun. The prolongation of these rays into the room makes up another cone similar in shape to the first, and if this cone be intercepted by a screen perpendicular to the line joining the hole with the centre of the sun, the image formed will be a circle. If the rays are intercepted by an oblique plane, as in the figure, the image is elliptical, but it never takes the form of the hole when that is small.

In accordance with this principle, we find the illuminated patches of earth formed by light passing between the leaves in a forest of a circular or elliptical shape. In an eclipse of the sun, when the visible portion of the sun is of crescent shape, the patches of light all assume the crescent form; that is, they are images of the visible part of the sun.

458. Camera and Lens. — If a double-convex lens be placed in the aperture and a screen in the focus, the image will be brighter and more sharply defined.

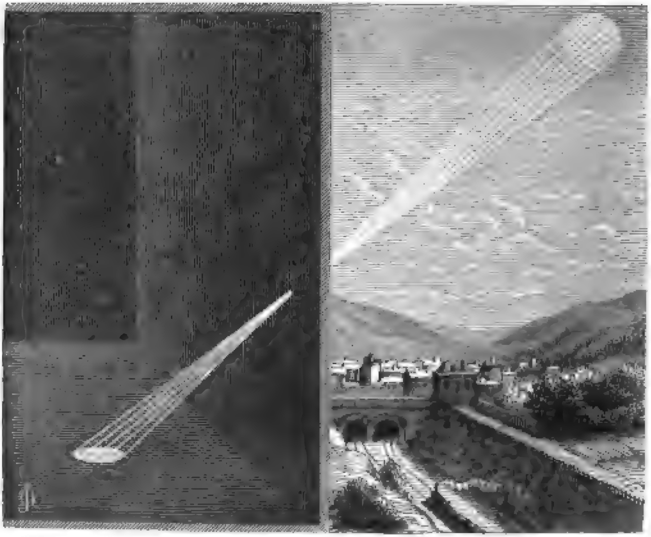

Fig. 316.

If now, instead of the room, we substitute a box, we shall have the ordinary camera used in sketching the outlines of a landscape or building, and also employed in the various branches of photography. This latter use constitutes its principal importance at the present time.

When the rays of light passing into the camera through the lens are allowed to strike upon a mirror inclined at an

angle of 45°, they are reflected to the top of the box, and if a plate of ground glass be inserted there an upright image will be formed.

This image can very easily be copied by means of tracing-paper laid upon the glass.

A camera arranged in this way is very convenient for artists in sketching landscapes. It may also be used as a source of amusement in representing street scenes with all their life and motion. The box containing the mirror is generally made to slide in the box to which the lens is fitted, so that the focus can readily be found.

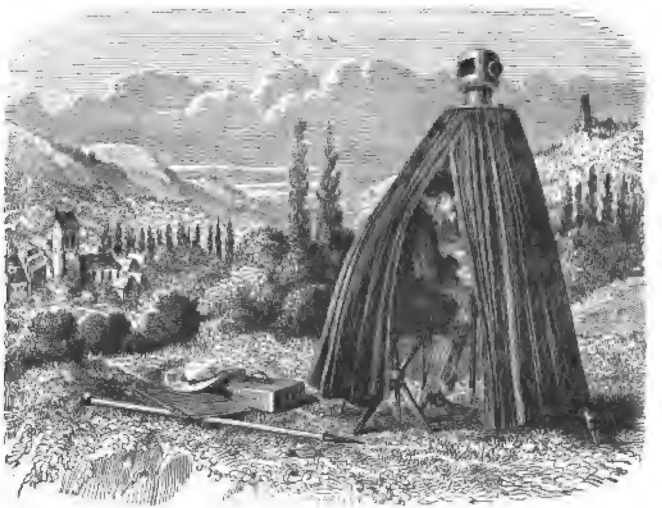

Fig. 317.

459. **Portable Camera for Artists.** — For taking views the camera obscura should be light and portable. The best form is that shown in Fig. 317. It consists of a sort of portable tent of black cloth, within which is a table for receiving the image, and at the top of which is a tube bearing a prismatic lens, that produces the combined effect of the mirror and lens. The figure projected upon the table may be traced out with a pencil on a sheet of white paper.

Fig. 318 shows the course of the rays in forming the image. The rays coming from the object, *A B*, fall upon the convex face of the lens and are converged, and in this state they reach the plane surface, *m*, which is inclined to the horizon. Being totally reflected from the surface, *m*, they emerge through the slightly concave surface below, and go to form an image, *a b*, on the table, *P*. A sheet of paper is spread on *P* to receive the image, and on it the outlines may be traced.

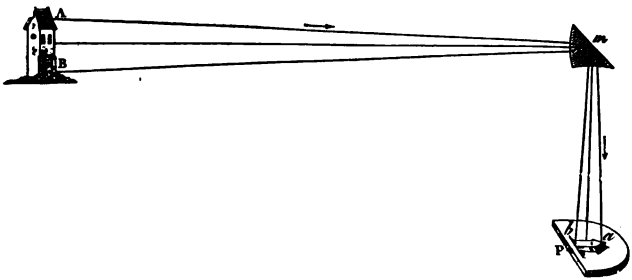

Fig. 318.

460. The Photographer's Camera. — Fig. 319 represents the form of camera used in the process of photographing. It consists of a rectangular wooden box, *C*, to one face of which is attached a tube, *A*, bearing a lens. which forms the image. The opposite face of the box consists of a sliding drawer, *B*, holding a plate of ground glass, upon which the image, *E*, is thrown, and by drawing it out or sliding it in, the picture may be rendered distinct upon the glass. The final adjustment in getting the plate of glass in the focus is made by means of the pinion, *D*. When the image is clearly defined, the plate of glass is removed, and a plate of metal or glass introduced which has previously been prepared by certain chemical processes so as to be sensitive to the actinic property of the sun. The image is then imprinted on this plate.

There are two kinds of photographic pictures, *positive* and *negative*. *Positive* pictures are those that have their lights

and shades in their proper relative position; *negative* pictures are those in which the lights and shades are reversed in position.

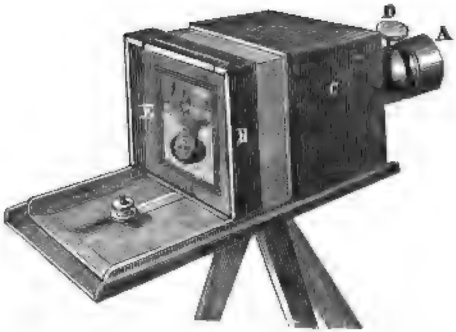

Fig. 319.

A negative picture is taken on glass in the way described; it is then placed upon paper chemically prepared, and exposed to the sun's rays, thus producing a *positive* picture. The full details of the processes involved in the art of photography belong to the province of chemistry rather than physics, and will not be considered here.

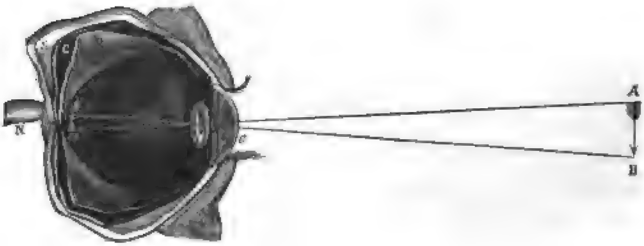

Fig. 320.

461. **The Eye** is a collection of refractive media, by means of which we are made acquainted with the external world through the sense of sight.

As an optical instrument the eye is not, as generally supposed, theoretically perfect; it has faults, to some extent, of spherical and chromatic aberration, but its remarkable properties of self-adapta-

tion and self-adjustment make it a practical instrument of marvellous power.

The shape of the eye is spherical, with a slight protuberance in front; the average diameter of the human eye is a little less than nine tenths of an inch. Fig. 320 represents a section of an eye, with some of the coverings thrown back so as to show the position of the parts.

The front part of the eye is limited by a perfectly transparent membrane, *c*, called the *cornea*. The remainder of the exterior coating is an opaque white membrane, *S*, called the *sclerotic coat;* this is a tough, white, opaque, fibrous membrane. The cornea is set in the sclerotic coat, as a watch-glass is set in its frame.

Immediately behind the cornea is a transparent fluid, limpid as water, called the *aqueous humor*. In this floats a circular curtain, *h i*, attached by its outer edge to the sclerotic coat, and having a small circular opening at its middle. The curtain is called the *iris*, and the hole in its centre is called the *pupil*. The iris gives color to the eye, being black, blue, gray, etc. It is muscular, and by the contraction and expansion of the fibres, the pupil may be enlarged or diminished; it is through the pupil that rays of light enter the eye.

Behind the iris is a double-convex lens, *o*, called the *crystalline lens;* it is of the consistence of gristle, perfectly transparent, more curved behind than in front, and is denser towards its middle than at the edges. This lens, with the cornea, serves to converge the rays to foci behind it. Immediately behind the crystalline lens is a medium *nearly* filling the remainder of the cavity of the eye, called the *vitreous humor;* it is of the consistence of jelly, and perfectly transparent, permitting the rays to pass through it. These humors keep the eye symmetrical.

Immediately behind the vitreous humor is a thin white expansion of the *optic nerve*, *N*, lining nearly all of the sclerotic coat; this is called the *retina*, and is the seat of vision.

Behind the retina, and between it and the sclerotic coat, is a fine velvety coating called the *choroid coat*, covered with a black pigment, which absorbs the rays that pass the retina, preventing internal reflection. The sensation of sight is conveyed to the brain by the optic nerve, which goes to the brain.

462. The Mechanism of Vision. — The action of the eye is similar to that of the camera obscura, except more perfect: the *pupil* corresponds to the hole in the shutter, the *crystalline lens* and *cornea* form the image, and the retina is the screen on which the image falls. The *iris* corresponds to the diaphragm, which is used in the ordinary camera to moderate the light by cutting off all the rays except those which fall upon the central part of the lens.

The image on the retina is inverted, as shown in Fig. 320, for the rays cross as in the ordinary camera. This can be proved by taking the eye of an ox and paring off the back of it so as to nearly expose the retina; then hold in front of the eye a candle, its inverted image can be seen in the back of the eye.

Many theories have been proposed to explain why we do not see inverted images of objects. The fact that we always see images erect seems to be due to the interpretation by the mind of the sensation carried to the brain by the optic nerve. The sense of touch is also supposed to assist in determining correctness of position.

463. Distinct Vision. — The eye adapts itself to different distances by changing the convexity of the crystalline lens by muscular contraction and relaxation. For distant objects the lens is made less convex, as the rays are more readily brought to a focus upon the retina; but for near objects the lens is rendered more convex on account of the greater difficulty of securing the focus.

The eye adjusts itself to different degrees of intensity by varying the size of the pupil. If the light is too intense, the iris contracts the pupil so that less will enter; if too weak, it expands the pupil, thus admitting more light.

Each impression made upon the retina lasts about an eighth of a second; if it last a less time than this, there is no distinctness of outline. When the impressions succeed one another with greater rapidity than this, one continuous impression will be produced. Falling drops of rain appear like liquid threads; a stick whirled round rapidly with a spark of fire at one end gives a circle of light, as mentioned in Art. 421. The spokes of a carriage-wheel revolving with great velocity cannot be distinguished.

464. Near-sightedness and Far-sightedness. — Persons who see distinctly only at very short distances are said to be *near-sighted;* and those who can only see distinctly at a long distance, *far-sighted.*

Near-sightedness comes from too great convexity of the cornea or crystalline lens, or both; also from too great an elongation of the eyeball, so that the retina is too distant. The effect is to bring the rays to foci before reaching the retina, giving an indistinctness to vision. This defect is remedied by holding the object very close to the eye, or by using spectacles with concave lenses, which diverge the rays before falling upon the cornea, and thus enable the media of the eye to bring them to foci upon the retina. If the eyes are unlike, the lenses should be of different power.

Far-sightedness is a defect just the reverse of near-sightedness. It arises from too great flatness in the cornea or crystalline lens, or it is due to the retina being too near the cornea on account of the flatness of the whole eyeball, so that rays of light are brought to foci behind the retina. This defect is remedied by using spectacles with convex lenses.

465. Vision with two Eyes. — An image of every object viewed is formed in each eye; yet vision is not double, but single.

This is undoubtedly owing to the way the eyes are connected with the brain and with each other by means of the optic nerve. They are not so much two distinct organs as one double organ, both parts of which are associated for the purpose of performing a *single* act.

466. The Stereoscope. — *Simultaneous vision* with two eyes is supposed to give us the idea of *relief*, or form of objects, — a view which receives confirmation from the action of the *stereoscope*.

This is an apparatus employed to give to flat pictures the appearance of relief, that is, the appearance of having three dimensions.

When we look at an object with both eyes, each eye sees a slightly different portion of it. Thus, if we look at a small cube, as a *die*, for example, first with one eye and then with the other, the head remaining fast, we shall observe that the perspective of the cube is different in the two cases. This will be the more apparent the nearer the body.

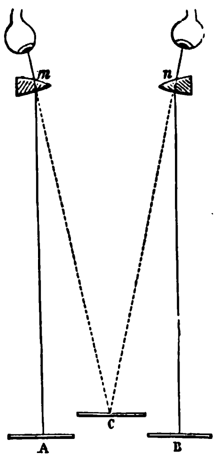

Fig. 321.

If the cube has one face directly in front of the observer, and the right eye is closed, the other eye will see the front face and also the left-hand face, but not the right; if, however, the left eye is closed, the other eye will see the front face and also the right-hand face, but not the left. Hence we know that the two images formed by the two eyes are not absolutely alike. It is this difference of images which gives the idea of relief in looking at a solid body.

If, now, we suppose two pictures to be made of an object, the one as it would appear to the right eye and the other as it would appear to the left eye, and then look at them with both eyes through lenses that cause the pictures to coincide, the impression is precisely the same as though the object itself were before the eyes. The illusion is so complete that it is almost impossible to believe that we are simply viewing pictures on a flat surface.

Such is the theory of the stereoscope. Fig. 321 shows the course of the rays in this instrument as just described. *A* represents a picture of the object as it would be seen by the right eye alone; *B*, a picture of the same object as it would be seen by the left eye alone; *m* and *n* are lenses which deviate the rays so as to make the pictures appear to be coincident at *C*.

The lenses *m* and *n* ought to be perfectly symmetrical, and this result is attained by cutting a double-convex lens in two, and placing the right-hand half before the left eye, and the other half before the right eye. The pictures must be perfectly executed, which can be done only by means of the photographic process. The pictures are made by using two cameras inclined to each other in the proper angle.

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- Definition.
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CHAPTER IX.

ELECTRICITY.

Part I. — MAGNETISM.

SECTION I. — NATURE OF ELECTRICITY. — GENERAL PROPERTIES OF MAGNETS.

467. **Nature of Electricity.** — The real nature of electricity is difficult to determine. It manifests itself chiefly in attractions and repulsions, but it is also recognized by its luminous and heating effects, by its power in chemical decompositions, and, at times, by the violence of its action.

All electricity has the characteristic of polarity, or two-sidedness, and is now generally conceded to be due to molecular motions. Several theories have been advanced in regard to its nature, some of which will be considered hereafter.

We may conveniently separate it into three divisions: Magnetism, which, although formerly ascribed to a special force, is now identified with electricity; Frictional Electricity; and Dynamical Electricity.

468. **Natural and Artificial Magnets.** — *Natural magnets* are certain ores of iron, and are generally known under the name of loadstones.

The magnet is so called from the town of Magnesia, in Lydia, where it was first noticed by the Greeks. It is known in chemistry as magnetic oxide of iron. It is now found in

Artificial magnets are bars of tempered steel, to which the property of the natural magnet has been imparted. The artificial magnet is far more valuable and powerful than the natural magnet, and is generally used in practice.

Steel is a mixture of iron with a small quantity of carbon, and when heated and then plunged into water, it becomes exceedingly hard, and capable of retaining the magnetism that may be imparted to it. Steel magnets are ***permanent magnets.***

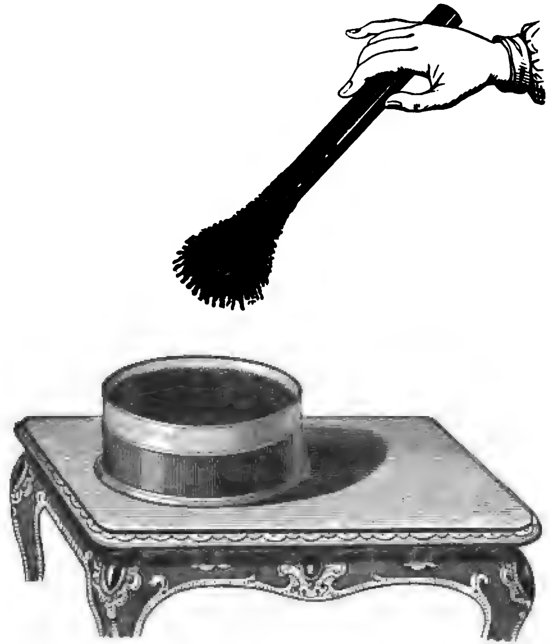

Fig. 322.

Magnets may be made of soft iron or untempered steel, but they do not retain their magnetism when the exciting cause is removed. Such magnets are called ***temporary magnets.***

Artificial magnets for experiment are made of oblong bars, from twelve to fifteen inches in length, as represented in Figs. 332, 333.

Fig. 334. Sometimes they are made in the form of a thin long needle, as shown in Fig. 324. This is the form in which they are constructed for pointing out the direction of the magnetic meridian, as in compasses. In this form they are also used in many magnetic experiments.

469. Distribution of Force in Magnets. — The force with which a magnet attracts iron is not the same in all of its parts. The attraction is strongest at its extremities, from which it decreases towards its middle, where it is nothing.

Fig. 323.

This may be shown by plunging one end of a magnetized bar into iron filings; on withdrawing it, the filings will be seen adhering to it in long filaments, as shown in Fig. 322. If the entire bar be rolled in the filings, it will be found that they adhere to both ends, but not to the middle.

The two ends, where the attraction is strongest, are called *poles*, and the central part, where the attraction is nothing, is called the *equator*, or the *neutral line*, and the magnet is said to exhibit *polarity*.

Every magnet has two poles and one neutral line, whether the magnet be natural or artificial. Sometimes besides the two prin-

artificial magnets these arise from inequality of temper in the steel bars, or from want of proper care in magnetizing them. We shall suppose each magnet to have but two poles.

We shall presently see that a magnet when freely suspended always assumes a position with one pole pointing towards the north and the other towards the south. The end pointing towards the north is called the *north pole*, and the other end the *south pole*.

To distinguish between the two poles of an artificial magnet, the north pole end is generally marked with a + sign or with the letter N.

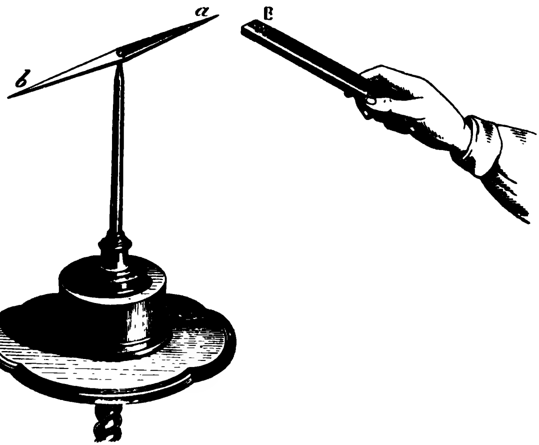

Fig. 324.

The action of a magnet upon iron takes place through intermediate bodies. If a magnetized bar be covered with a sheet of paper, and then fine iron filings be sifted uniformly over the paper, they will be seen arranging themselves in regular curves around each pole, as shown in Fig. 323. No action is observed about the neutral line, the filings falling there as on any other surface.

470. Action between Magnets. — If we compare the action of the two poles upon soft iron, we observe the same phenomena, — both will attract ordinary iron. It is not so, however, when we compare the action of two magnets upon

balanced on a pivot (Fig. 324), we present in succession the two poles of a magnetized bar, held in the hand, we observe the curious phenomena that if the pole, *a*, of the needle is attracted by the pole, *B*, of the bar, the pole, *b*, will be repelled by it; if the pole, *a*, is repelled, the pole, *b*, will be attracted.

471. Hence the following law: *Like poles repel, and unlike attract each other.*

472. **Effect when a Magnet is broken.**—If we break a magnet into pieces, every piece becomes a perfect magnet with its two poles and neutral line, as shown in Fig. 325. If,

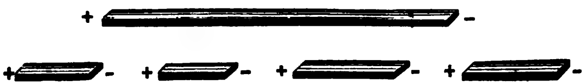

Fig. 325.

now, these pieces are still further divided, the number of magnets will be equal to the number of divisions, and so on indefinitely. Thus, we cannot resist the conclusion that each molecule is a magnet complete in all its parts.

In Fig. 326 we have a magnet, *N S*, showing the polarized molecules, the white halves representing one pole, the north or positive pole, and the black the south or negative pole.

Fig. 326.

The opposite polarities neutralize each other at the centre, but strongly manifest themselves at the ends of the magnet.

All the molecules exact a positive force towards *N* and a negative towards *S*.

473. **Magnetic and Diamagnetic Bodies.**—Magnetic substances are those which are attracted by a magnet, as iron, steel, nickel, and cobalt. By using very powerful magnets Faraday found that certain substances are repelled by magnets, such as bismuth, antimony, zinc, tin, mercury, lead, silver, copper, gold, and arsenic. These are called diamagnetic.

The greatest degree of repulsion is seen in bismuth, and attraction in iron. But the repulsion between the magnet and bismuth is not so strong as the attraction between the magnet and iron.

474. Magnetism by Induction. — If a ring of soft iron be presented to a magnet, as an iron ring, it converts it into a magnet. If a second ring be presented to the first, it is in like manner converted into a magnet, and so on for a third, fourth, etc. The magnets thus formed adhere to one another, as shown in Fig. 327. If the bar be removed, the rings cease to be magnets, the chain falls to pieces, and the rings separate. This mode of exciting magnetic phenomena is called magnetizing by *induction.*

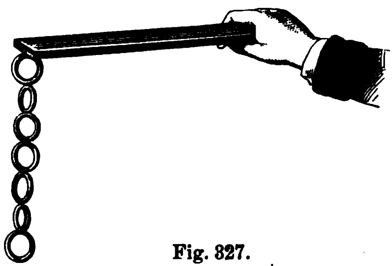

Fig. 327.

Induction can be explained by supposing that in the unmagnetized rings the two opposite or polar forces neutralize each other, and no magnetic action is exhibited; but when they are brought near the magnet these forces separate, and each ring becomes a magnet, and unlike poles attract one another, as seen in the figure. The inducing magnet loses none of its magnetic force.

475. The Coercive Force. — Soft iron brought in contact with a bar magnet becomes a magnet instantly, and on being removed returns to its neutral condition, ceasing to be a magnet. With hardened steel the reverse is the case; it takes considerable force and some time to render it a magnet, and on being removed from the bar it continues to be a magnet. To make the magnetism complete in steel, it must be rubbed with one of the poles of a magnet.

This force which offers a resistance to the separation of the two polarities in magnetic bodies, and also tends to prevent a recombination when once separated, is called the *coercive force.*

Summary. —

Nature of Electricity.
How Manifested.
Characterized by Polarity.
How Divided.

Natural and Artificial Magnets.
Definition of each.
Permanent and Temporary Magnets.
Forms of Artificial Magnets.

Distribution of Force in Magnets.
Polarity proved by Experiment.
Position assumed by Magnet when freely suspended.
Action of a Magnet through Bodies proved by Experiment.

Action between Magnets.
Shown by Experiment.
Law of Magnetic Attraction and Repulsion.

Effect when a Magnet is broken.
Every Piece a New Magnet.
Illustrated by Figure.
Polarized Molecules illustrated by Figure.

Magnetic and Diamagnetic Bodies.
Definition and Examples of each Class.

Magnetism by Induction.
Illustrated by Figure.
Explanation of Induction.

Coercive Force.
Illustrated and defined.

SECTION II. — TERRESTRIAL MAGNETISM. — COMPASSES.

476. Directive Force of Magnets. — When a permanent magnet is balanced so that it can turn freely in a horizontal direction, it assumes, after a few oscillations, a determinate direction, which is very nearly north and south.

Fig. 328 shows the manner of balancing a needle, and indicates the north and south direction which it assumes.

If, instead of mounting the needle on a pivot, it be attached to a piece of cork and placed in a vessel of water, so that the needle may float in a horizontal position, it will turn itself slowly around and come to rest in the same general direction as though it were balanced on a pivot. In this experiment it will be found that the needle once in the meridian does not advance either towards the north or south. Hence we infer that the force exerted upon the needle is simply a *directive* one.

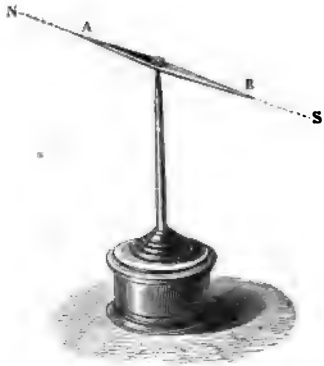

Fig. 328.

The force which causes a movable magnet to direct itself north and south is called the *directive force.*

Since the phenomenon described takes place at all points of the earth's surface, the earth has been regarded as an immense magnet, having its north and south poles near the north and south poles of the earth, and a neutral line near the equator. This immense magnet, acting upon the smaller magnets described, would produce all of the effects observed. When we come to explain the action of electric currents, it will be seen that there is another explanation of the *directive* power of the earth.

According to the law that ***like poles repel and unlike attract***, the pole, A, in the figure is really the south pole, and the pole, B, the north pole of the needle.

But in practice it is generally customary to call the end of the magnet pointing towards the north, the ***north pole***, and the one pointing towards the south, the ***south pole.***

477. Magnetic Meridian.—Declination.—Variations. —When a balanced magnetic needle comes to a state of rest, it points out the line of magnetic north and south. If a plane be passed through the needle in this position and the centre

of the earth, it is called the plane of the *magnetic meridian*, or simply the magnetic meridian.

This does not, in general, coincide with the plane of the true meridian, which is determined by a plane passing through the place and the axis of the earth. The angle which the magnetic meridian at any place makes with the true meridian of the same place is called the *declination of the needle*. In short, the declination of the needle is its variation from true north and south. This is different at different places on the earth, and even at the same place at different times.

When the north end of the needle points to the east of true north, the declination is said to be *to the east;* when to the west of true north the declination is said to be *to the west*.

There is a line running from near Cleveland, Ohio, to Charleston, S. C., along which the needle points to the true north; this is called a line of *no declination.*

The line of no declination is travelling slowly to the westward at a rate which would carry it around the globe in about 1000 years. For all points of the United States east of the line of no declination, the declination of the needle is to the west; for all points to the west of it, the declination is to the east; that is, the north end of the needle in all cases is inclined towards the line of *no declination.*

For all points in the United States to the east of the line of no declination, the declination is slowly increasing, while for all points to the west of it, the declination is slowly decreasing.

Besides this slow change in declination, the needle undergoes slight changes, some of which are pretty regular and others very irregular. In our latitude the north end of the needle moves towards the west during the early part of every day, through an angle of ten or fifteen minutes, and moves back again during the latter part of the day. This is called the *diurnal variation*. In the southern hemisphere this motion is reversed. There is also a small change of similar character which takes place every year, called the *annual* variation.

Irregular changes are called *perturbations.* They usually take

place during thunder-storms, during the appearance of the aurora borealis, and in general, when there is any sudden change in the electrical condition of the atmosphere.

478. The Compass. — The property possessed by magnets of arranging themselves in the magnetic meridian has been utilized in the construction of COMPASSES.

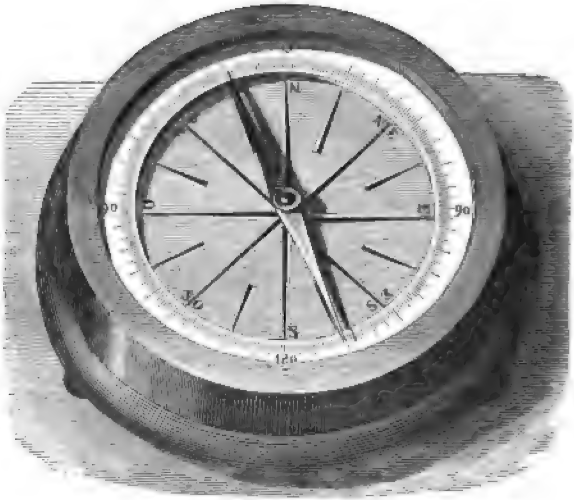

Fig. 329.

Fig. 329 represents a compass. It consists of a compass-box, having a pivot at its centre, on which is poised a delicate magnetic needle. Around the rim of the box is a graduated circle, whose diameter is somewhat less than the length of the needle, and of which the pin is the centre. The pin is of hard steel, carefully pointed; a piece of hard stone is let into the needle, in which is a conical hole to rest upon the pivot, to diminish the friction between the needle and its support. In addition to the graduation on the circle, the bottom of the box is divided into sixteen equal parts, indicating the *points of the compass.*

This instrument under various forms is used for a great variety of purposes. It is used in navigation, in surveying, and is of importance to the traveller and explorer, to say nothing of its use in mining.

The magnetic declination at any place may easily be found when the true meridian is known. This is found by astronomical methods, by taking observations of the north polar star, or the sun, and an instrument called the declination compass is used. This form of compass has a telescope turning on a horizontal axis in a vertical plane. Let the compass be so placed that the line, *N S*, coincides with the true meridian; then when the needle comes to rest, the reading under the head of the needle will be the declination required. In the figure, if we suppose *N S* to be in the true meridian, the declination is 19° west.

479. The Dipping Needle. — When a steel needle, mounted as shown in Fig. 328, is carefully balanced before being magnetized, it is found, after being magnetized, to incline downwards or to *dip*. This dip is towards the north in our latitude; that is, the north end of the needle dips or inclines. The defect of dipping in the compass is remedied by making the other end of the needle a little heavier, by adding a movable weight, as a piece of wire wound round the needle and capable of sliding along it.

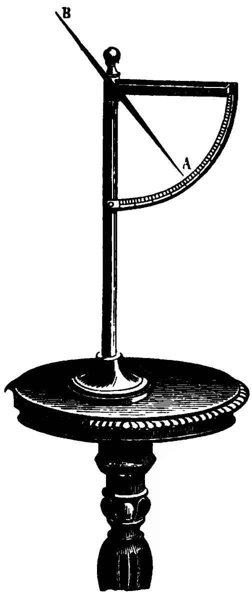

Fig. 330.

To show the dip and to measure it, the needle is mounted in the way indicated in Fig. 330. The needle is suspended on a horizontal axis, so that it can move up and down freely, and the amount of the dip is indicated by a graduated circle or quadrant. The dip indicated in the

figure is 54°, which is the angle made by the needle with the horizon. At any place the dip will be the greatest possible when the needle vibrates in the plane of the magnetic meridian.

The dip varies in passing from place to place, increasing as we approach the magnetic poles of the earth, where the dip is 90°; that is, the needle is perpendicular to the horizon. At the magnetic equator it is horizontal.

Action similar to that exerted by the earth on the needle is shown in Fig. 331. We have here three positions of the dipping needle represented upon a bar magnet. At the ends of the magnet the positions of the needle are the same as when over the

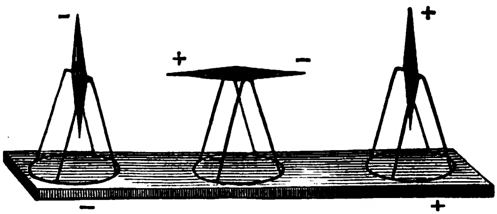

Fig. 331.

magnetic poles of the earth. The centre position corresponds to the position of the needle when over the magnetic equator. The dipping needle follows the law that unlike poles attract and like repel.

Summary. —

Directive Force of Magnets.

Illustrated by a Needle turning on a Pivot.

Illustrated by a Needle attached to a Piece of Cork which is floated on Water.

Earth as a Magnet.

Poles of the Needle.

Magnetic Meridian.

Definition.

True Meridian.

Definition.

Declination of the Needle.

Definition.

East and West Declination

Line of no Declination.
  Situation.
  Westward Progress.
Diurnal Variations of the Needle.
Annual Variations of the Needle.
Irregular Variations of the Needle.
Compass.
  Construction and Use.
  Method of finding the True and Magnetic Meridians.
The Dipping Needle.
  Explanations.
  Construction.
  Action when approaching the Magnetic Poles.
  Action similar to the Earth's shown between a Bar Magnet and Dipping Needle.

SECTION III. — METHODS OF IMPARTING MAGNETISM.

480. Magnetizing by Terrestrial Induction. — To MAGNETIZE a body is to impart to it the properties of a magnet, that is, to impart to it the property of attracting magnetic bodies.

The only substances that can be permanently magnetized are steel and the compound oxide of iron, which constitutes the loadstone. A body capable of being magnetized may be converted into a magnet by the inductive influence of the earth, or more rapidly by being rubbed by another magnet, or, finally, by the action of dynamical electricity, in which case the operation is instantaneous.

Natural magnets owe their magnetism to the slow action of the earth, which polarizes the molecules. The magnetic action of the earth is so great as to be used successfully in forming artificial magnets.

To use this principle, we place a thin bar of iron in the magnetic meridian and incline it to the horizon by an angle

equal to the dip. In this position the earth acts upon it by induction, the lower end manifesting south polarity (in our latitude), and the upper end, north.

The magnetism thus induced is only temporary; for if the bar be moved from its position, the opposite polarities neutralize each other. If, however, when the bar is in position, it be struck smartly by a hammer, or if it be violently twisted, sufficient coercive force may be developed to retain the induced magnetism for a time.

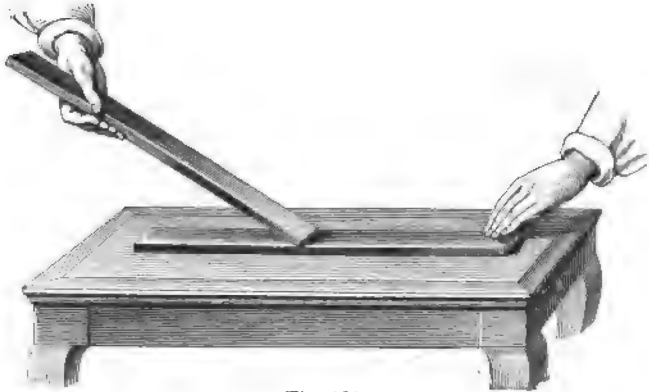

Fig. 332.

481. Magnetizing by Friction. — Bars of steel, and needles for compasses, are usually magnetized by rubbing them with other magnets. The three methods are called the methods by *single touch*, by *separate touch*, and by *double touch*.

To magnetize a steel bar by *single touch*, we hold the body to be magnetized in one hand, and with the other we pass over it a powerful bar magnet, as shown in Fig. 332. After several repetitions of this process, always in the same direction, the steel is found to possess all the properties of a magnet. These properties are the more durable in proportion to the hardness of the steel.

To magnetize a steel bar by *separate touch*, we bring the

two opposite poles of two magnets of equal force in the middle of the bar to be magnetized, and then move them simultaneously to the opposite ends of the bar.

To magnetize a body by *double touch*, we make use of two magnetized bars, which are placed with their opposite poles in contact with the bar at its middle point, being kept at a fixed distance by a piece of wood placed between, as shown in Fig. 333; the combined bars are then moved alternately

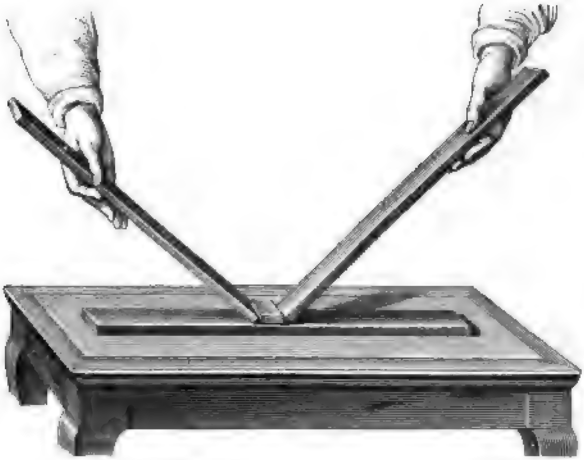

Fig. 333.

in opposite directions to the two ends of the bar, and the operation is repeated several times, finishing in the middle of the bar. Care must be taken to apply the same number of touches to each end of the bar.

The method of magnetizing by dynamical electricity will be treated of under the head of Electrical Currents.

482. Magnetic Battery. — Armatures. — A Bundle of Magnets, consisting of a group of magnetized bars united so that their poles of the same names may be coincident, is called a *magnetic battery*.

Sometimes these bundles are composed of straight bars,

like that shown in Fig. 332, and sometimes they are curved in the shape of a horse-shoe, as shown in Fig. 334.

Magnets, if abandoned to themselves, would lose in a short time much of their power; hence it is that *armatures* are employed.

An ARMATURE is a piece of soft iron placed in contact with the poles of a magnet. Thus, *a b*, in Fig. 334, is an *armature*.

The poles, acting by induction upon the armature, convert it into a magnet whose poles are of the opposite kind to those with which they come in contact. These two poles, reacting upon the poles of the magnet, *A B*, prevent the neutralization of the two polar forces, and thus preserve its magnetism. The armature is sometimes called a *keeper*.

Fig. 334.

If weights be attached to the keeper till it separates from the magnet, we can, from the number of pounds applied, judge of the power of the magnet.

For many kinds of magnetic experiment the horse-shoe form is preferable. It is also the form best adapted to the application of an armature or keeper.

When the magnets are in the form of bars they are arranged in pairs, and the armatures placed at the ends, as shown in Fig. 334.

Fig. 335.

The power of a magnet is liable to be lessened by heat or rough usage.

Summary. —

Magnetizing by Terrestrial Induction.
- Definition of the Term *Magnetize.*
- Substances that can be permanently magnetized.
- Methods of Magnetizing.
- Natural Magnets produced by the Earth's Action.
- Artificial Magnets produced by the Earth's Action.
- Coercive Power increased by Percussion and Twisting.

Magnetizing by Friction.
- By Single Touch.
- By Separate Touch.
- By Double Touch.

Magnetic Battery.
- Definition.
- Illustrated by Figure.

Armatures.
- Definition and Use.
- Armature and Horse-shoe Magnet illustrated by Figure.
- Armature and Bar Magnet illustrated by Figure.

ELECTRICITY.

Part II. — FRICTIONAL ELECTRICITY.

SECTION I. — ELECTRICAL PROPERTIES.

483. Discovery of Electrical Properties. — About 500 B. C., THALES of Miletus observed that when amber was vigorously rubbed with wool, it acquired the property of attracting light bodies, such as small pieces of paper, barbs of quills, straws, and the like.

This was the extent of the knowledge on the subject until the end of the sixteenth century, when WILLIAM GILBERT, an English physician, called anew the attention of scientific men to the properties of amber, and showed that a great number of other substances, such as glass, resin, silk, sulphur, etc.,

acquired the power of attracting light bodies, on being rubbed with woollen cloth or cat's skin.

To repeat these experiments, rub a tube of glass or a stick of sealing-wax with a piece of woollen cloth, then present them to light bodies, as shreds of gold-leaf, barbs of quills, or fragments of paper, and the latter will be seen to approach and adhere to the excited glass or sealing-wax. The glass and sealing-wax are then said to be *electrified*. The manner of making these experiments is indicated in Fig. 336.

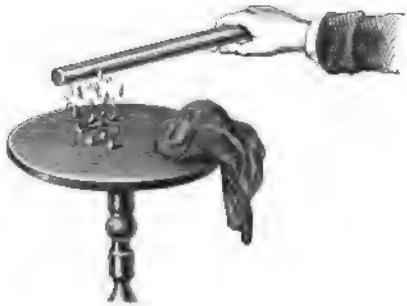

Fig. 336.

It will be seen hereafter that resin and other substances named above not only develop forces of attraction when rubbed, but also they become luminous, emit sparks, and display a number of other properties, all of which are known as electrical phenomena.

Since the beginning of the seventeenth century the progress of discovery in electricity has been rapid, and a multitude of new facts have been developed, which have been so well studied as to form a very extensive branch of natural science.

The Greeks applied the name *elektron* to amber, and hence the name *electricity* was given to the power of attraction exhibited by this substance.

484. Electroscope. — Electrical Pendulum. — An Electroscope is an apparatus for showing when a body is electrified.

The most simple electroscope is the Electrical Pendulum, which consists of a small ball of elder pith, suspended by a fine silk thread, as shown in Fig. 337. The thread is fastened to the upper end of a stem of metal, which stem has a support of glass.

presented to it; if it is electrified, the pith ball will be attracted, otherwise not. When the quantity of electricity is too small to produce sensible attraction upon the pith ball, more delicate instruments are sometimes employed.

485. Two Kinds of Electricity. — That there are two kinds of electricity may be shown by the action of glass and resinous bodies, after being rubbed, upon pith balls.

If a tube of glass be rubbed with a piece of silk, and then presented to the electrical pendulum (Fig. 337), the pith ball

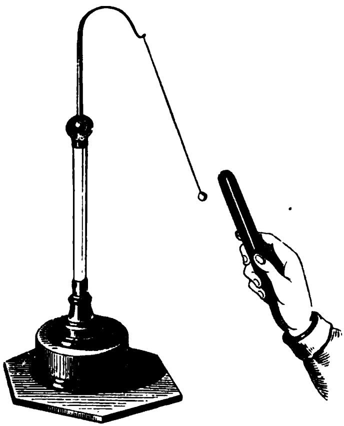

Fig. 337.

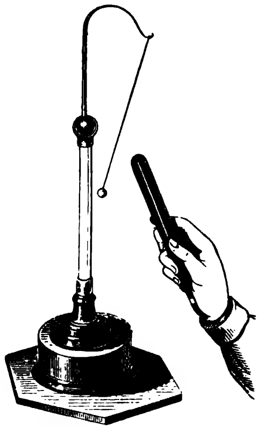

Fig. 338.

will at first be attracted, and after a short time it will be repelled, as shown in Fig. 338. The ball is then charged with the same kind of electricity as that in the glass.

If now a piece of a resinous body, as sealing-wax, be rubbed with flannel and brought near the excited pith ball, the latter is immediately attracted to the former. In like manner, if the sealing-wax be first presented to the pendulum, it will be attracted and then repelled. If then the glass be brought near the pith ball, attraction will be observed. This shows that the action of electricity, as developed in glass and resin, is different, the one repelling when the other attracts.

The electricity developed in rubbing glass with a piece of silk has been named *vitreous electricity;* that developed by rubbing resin or sealing-wax with the flannel has been named *resinous electricity.* We now use the term *positive* (+) to designate *vitreous* electricity, and *negative* (—) to designate *resinous.*

486. The Gold-Leaf Electroscope.—When the quantity of electricity is too small to produce sensible attraction upon the pith ball, more delicate instruments are sometimes employed, like the gold-leaf electroscope.

It consists of a glass bottle or jar, closed at the top with a cork, through which passes a metallic rod; this terminates at the top in a ball of metal, and at its lower extremity in two slips of gold-leaf. The instrument is represented in Fig. 339.

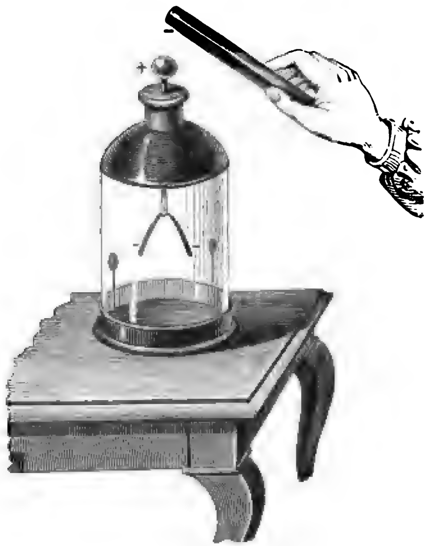

Fig. 339.

The cork and the whole top of the bottle are covered with a kind of varnish made by dissolving sealing-wax in alcohol. The varnish is laid on with a brush, and serves to make the bottle a better non-conductor. This kind of varnish is often used in electrical experiments to render glass non-conducting. Glass in a dry state is a good non-conductor, but it is apt to condense moisture from the air so as to become a conductor. When covered with any resinous varnish this trouble is removed.

487. Method of using the Gold-Leaf Electroscope.—To ascertain whether a body is electrified, we bring the ball of the

electroscope near it. If it is electrified, it acts upon the ball and its stem by induction, attracting the electricity of a contrary name into the ball, and repelling that of the same name into the gold leaves, which, being very light and electrified by the same kind of electricity, will diverge. This instrument is very sensitive, showing the slightest amount of electricity.

To test the *kind* of electricity in a body, bring it near the instrument and touch the ball with the finger while under the influence of the body. This will draw off the electricity of the same name which has been developed by induction, and leave that of a contrary name to that in the body, which is held in the ball by induction from the electrified body. The leaves will now collapse, not being electrified. If now the finger be removed and then the electrified body, the electricity retained in the ball will spread over the rod, leaves, and ball, and cause the leaves to diverge. Now, let a glass rod be rubbed with silk, so as to excite positive electricity, and then let it touch the ball of the electroscope.

If the leaves diverge more, the electricity in them before was positive, and that of the body in question was consequently negative. If, however, the leaves approach each other, the electricity in them before was negative, and consequently that in the body experimented upon was positive.

The metallic post, at the left of the leaves, is connected with the ground, and serves to remove an excessive charge from the leaves. The air in the jar is kept dry by quicklime or some other substance that absorbs moisture placed within it.

488. Law of Electrical Action. — From the results of the preceding experiments, and also from numerous similar ones, we have the following law of electrical action: *Two bodies charged with the same electricity repel each other; two bodies charged with opposite electricities attract each other.*

489. Conductors. — Insulators. — CONDUCTORS, or *conducting substances*, are those which permit electricity to pass freely through them.

INSULATORS, or *non-conducting substances*, are those which do not permit electricity to pass freely through them.

Electrified bodies return instantly to a neutral state when brought

into contact with the earth, or when placed upon supports of metal, charcoal, or any moist substance whatever. They remain in an electrified condition for a long time when placed upon supports of glass, resin, sulphur, or when suspended by silken cords.

From these facts we conclude that metals, charcoal, and the like, permit the electricity to pass freely through them, while glass, resin, sulphur, etc. oppose its passage. The latter class of bodies are not entirely incapable of conducting electricity, but they are extremely poor conductors. When an electrified body is surrounded by non-conductors it is said to be *insulated*, and any non-conducting support of an electrified body is therefore called an *insulator*.

The best conductors of electricity are the metals; after these come plumbago, well-calcined carbon, acid and saline solutions, water either in a liquid or vaporous form, the human body or animal tissues, vegetable substances, and in general, all moist or humid substances.

The worst conductors, or best non-conductors, are resins, gums, india-rubber, silk, glass, precious stones, spirits of turpentine, oils, air, and gases when perfectly dry.

490. Hypothesis of Two Electrical Fluids.—To account for electrical phenomena several theories have been proposed. The two principal ones are the *one-fluid* theory of FRANKLIN and the *two-fluid* theory of SYMMER.

The former maintains the existence of only one electric fluid, whose particles are self-repellent. This fluid exists in all bodies in varying proportion. In its natural state every substance has exactly its own quantity; but when electrical excitement occurs, it is *positively* electrified if it has an excess of its natural quantity, and *negatively* electrified if there is a deficiency. Equilibrium is restored in positive bodies by parting with the excess, and in negative bodies by supplying the deficiency from surrounding bodies.

The *two-fluid* theory maintains the existence of two electric fluids which exist in unexcited bodies in equal quantities in a state of neutralization. When separated they attract each other, but the particles of either fluid repel one another.

These two fluids were at first named the *vitreous* and the *resinous* fluids, but more recently they have been called the *positive* and the

negative fluids, the vitreous being called positive and the resinous negative. These names were given by FRANKLIN, the better to express their opposite characters.

Both theories are gradually being abandoned, although their terms are often used as a matter of convenience in describing electrical phenomena, but not with the meaning originally intended.

The theory of SYMMER has generally been preferred by physicists to that of FRANKLIN.

Electricity, as was stated at the beginning of the chapter, is undoubtedly due to molecular motion of some sort, and is recognized by its manifestations of polarity. We can regard it as a form of *energy*, just as we regard Gravitation, Cohesion, Chemical Affinity, Sound, Heat, and Light as only so many forms of *energy*.

When the two electricities are separated, the energy required to do the work of separation is converted into potential energy, since the bodies charged with opposite electricities attract each other; this potential energy becomes kinetic when the two bodies approach each other. We shall see further on that this electrical energy can be converted into other forms of energy, as heat, light, and chemical separation.

491. Two Kinds of Electricity always produced by Friction. — Whenever two bodies are rubbed together, both kinds of electricity are always produced at the same time and in equal quantities. When glass is rubbed with silk, the glass will manifest positive electricity and the silk negative.

In the following list any substance becomes positively electrified when rubbed with any of the bodies following, but negatively with any of those preceding.

1. Cat's-fur.	5. Cotton.	9. Shellac.	13. Caoutchouc.
2. Flannel.	6. Silk.	10. Resin.	14. Gutta-percha.
3. Ivory.	7. The hand.	11. The metals.	15. Gun-cotton.
4. Glass.	8. Wood.	12. Sulphur.	

492. Electricity developed by other Causes than Friction. — Electricity may be developed by pressure and cleavage; in fact, by any cause that disturbs the molecular arrangement

of bodies. A crystal of Iceland spar pressed between the fingers becomes positively electrified. When a piece of sugar is broken suddenly in a dark room, a feeble light is observable, which is due to the development of electricity at the moment of separating the molecules. If a plate of mica be quickly split, electricity is developed. Some minerals, particularly tourmaline and topaz, manifest electrical phenomena on being heated.

This fact was first discovered in the case of tourmaline, which first attracts and then repels hot ashes when placed among them. The electricity produced by the methods just mentioned is similar in its action to that produced by friction. Frictional electricity is sometimes called *statical* electricity because it can be retained for some time on excited bodies. Electricity produced by *chemical compositions* and *decompositions* of bodies will be considered under Dynamical Electricity.

493. Methods of electrifying Bodies. — Non-conducting bodies are electrified only by friction, but conductors may be electrified either by friction, by contact, or by induction.

In order to electrify a metal, it must be insulated; that is, it must be surrounded by non-conducting bodies, and it must be rubbed by an insulated body.

This may be effected by mounting the metal upon a stand of glass and rubbing it with a non-conductor, such as a piece of silk. Were the metal not insulated, the electricity would go to the earth as fast as generated, and were the rubbing body not a non-conductor, the electricity would pass off through the hands and arms of the experimenter.

The method of electrifying by contact depends upon the property of conductibility. If a conductor is brought in contact with an electrified body, a portion of the electricity of the latter is at once imparted to the former body. If the two bodies are exactly alike, the electricity will be equally distributed over both. If they differ in size or in shape, the electricity will not be equally distributed over both.

The method of electrifying bodies by induction is similar to that of magnetizing bodies by induction, and will be treated hereafter.

494. Accumulation of Electricity on the Surface of Bodies. — Experiment shows that when a body is electri-

fied, the electricity all goes to the surface of the body, where it exists in a thin layer, tending continually to escape. It actually does escape as soon as it finds an outlet through a conducting body.

Of the various experiments intended to show this fact, we select one that was first performed by COULOMB. He mounted a copper sphere upon an insulating rod of glass, as shown in

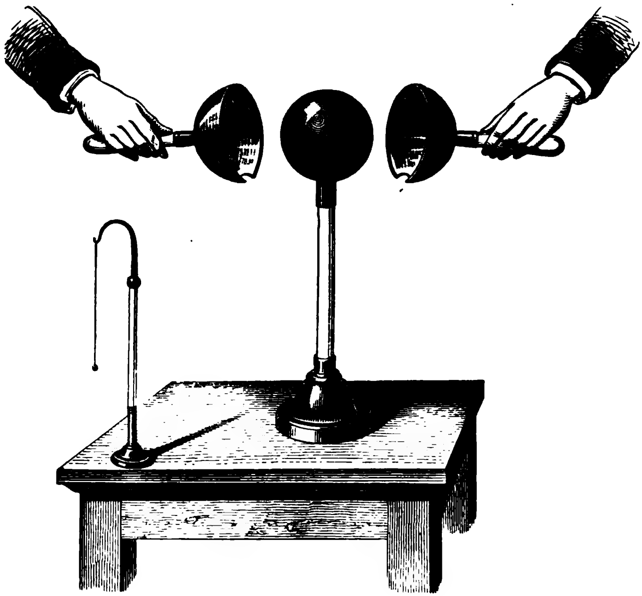

Fig. 340.

Fig. 340. He then provided two hollow hemispheres also of copper, which, when put together, exactly fitted the first sphere, and these he insulated by attaching them to glass handles. Having placed the hemisphere so as to cover the solid sphere, he brought the whole apparatus in contact with an electrified body till it was fully charged.

On removing the apparatus from the electrified body, he separated the two hemispheres abruptly, and applied to each in turn the elec-

trical pendulum, when he found that both were electrified. On testing the solid sphere in like manner, he could discover no trace of electricity; in other words, it was perfectly neutral. In taking away from the body its outer coating, he had removed every particle of its electricity, which proved that the electricity was entirely upon the surface.

Another fact which indicates the same conclusion is, that a hollow and a solid sphere of the same size and of the same material will be charged with exactly the same quantity of electricity when made to communicate with the same electrical source.

The following experiment was invented by FARADAY to prove that electricity is confined to the surface of bodies. A metallic ring (Fig. 341) is fixed upon an insulating stand; attached to this is a conical linen bag. A silk thread passes through the apex of the cone, so that the bag can be turned inside out as often as necessary without discharging the electricity. When the bag is electrified the electricity is found to be on the outside, and if we turn it inside out the same is true.

Fig. 341.

There are two exceptions to this rule. A hollow wire will not conduct electricity as well as a solid one of the same diameter. Electricity may be induced on the inner surface of a hollow conductor, if we place within it an electrified body insulated from the conductor.

495. Tension of Electricity.—When electricity is accumulated upon the surface of a body, it tends to escape with a certain force, which is named the *tension*.

The tension augments with the quantity of electricity accumulated. So long as it does not pass a certain limit, it is held by the resistance of the air, but if the tension passes this limit, the electricity escapes with a crackling noise and a brilliant light called the *electric spark*. In moist air the tension is not as great as in dry air, because some of the

electricity is slowly conveyed away by the moisture. Sir W. THOMSON asserts that the electricity is conveyed away more by the film of moisture on the insulators than by the dampness in the air. In a vacuum there is no resistance to the escape of electricity, and the tension is nothing. The electricity in this case passes off as fast as generated, with a feeble light.

496. Influence of the Forms of Bodies. — Power of Points. — The distribution of electricity over the surfaces of bodies depends upon their form. If a body is spherical, the fluid is equally distributed, as may be shown by an instrument called a *proof-plane*.

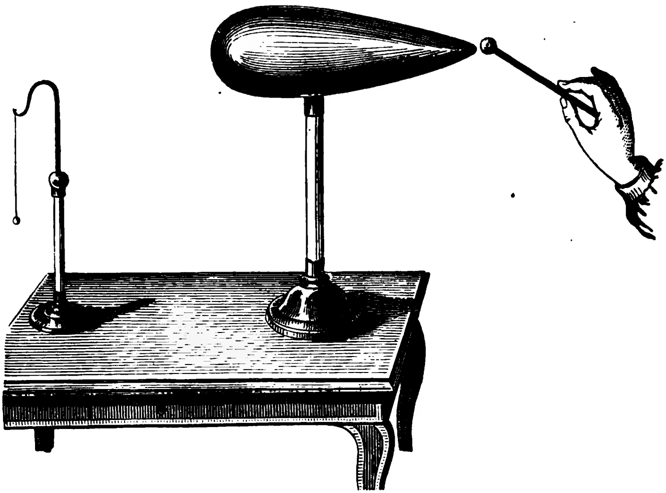

Fig. 342.

The proof-plane consists of a disk of gilt paper attached to the end of a rod of gumlac, which insulates well. Taking the rod in the hand, as shown in Fig. 342, it is applied successively at different points of the electrified surface, and after each contact it is presented to the electrical pendulum.

If the electrified body is a sphere, the same amount of attraction for the pith ball is shown, wherever the contact may be made; this shows that the proof-plane is equally charged

at every point of the sphere, and consequently it is inferred that the distribution is uniform over the whole surface.

When the body is elongated and pointed, as in Fig. 342, different results are obtained. In this case the proof-plane is more highly charged at the sharp end of the body than at any other point, showing a larger amount of electricity at the point than elsewhere.

In general, it may be shown that the greater the curvature of a surface at any part, that is, the nearer it approaches a point, the greater will be the accumulation of electricity there.

This shows that electricity tends to accumulate at, or to flow towards the pointed portions of bodies.

Summary. —

Discovery of Electrical Properties.

- By Thales of Miletus, in Amber.
- By Dr. Gilbert, in Glass, Resin, Silk, etc.
- Method of developing Electricity by Friction illustrated by Figure.
- Origin of the Name.

The Electroscope.

- Definition.
- Electrical Pendulum.
- Description.
- Method of ascertaining whether a Body is electrified.

Two Kinds of Electricity.

- Shown by the Electrical Pendulum and illustrated by Figure.
- Vitreous, or Positive Electricity; Resinous, or Negative Electricity.

Gold-Leaf Electroscope.

- Description.
- Method of using the Gold-Leaf Electroscope.
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Law of Electrical Action.

Conductors and Insulators.

- Definitions.
- Illustrations.
- Examples of Good and Poor Conductors.

Hypothesis of two Electrical Fluids.
Franklin's Theory explained.
Symmer's Theory explained.
Their Gradual Abandonment.
Relation of Electricity to Energy.
Examples.

Two Kinds of Electricity always produced by Friction.
Experiment with Glass and Silk.
List of Substances that will produce Electricity by Friction.

Electricity produced by other Causes than Friction.
By Pressure, Cleavage, Heat, and Chemical Composition and Decomposition.

Method of electrifying Bodies.
Conductors and Non-Conductors.
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Accumulation of Electricity on the Surface of Bodies.
Illustrated by Figure of Hemispheres and Globe.
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Tension of Electricity.
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Influence of the Forms of Bodies on the Distribution of Electricity.
In the Case of a Sphere.
When the Body is Elongated or Pointed.

SECTION II. — PRINCIPLE OF INDUCTION. — ELECTRICAL MACHINES.

497. **Induction.** — If an insulated conductor in a neutral state is brought near an electrified body, but not so near as to have a spark pass between them, the latter, acting upon the former, separates the two kinds of electricities, repelling the same kind and attracting the opposite kind. This operation is called INDUCTION, and it may take place not only at considerable distances, but also through non-conducting bodies, such as air, glass, and the like.

The method of electrifying bodies by induction is shown in

Fig. 343. On the right of the figure is the prime conductor of an electrical machine, which, as we shall see hereafter, is charged with positive electricity. On the left is a metallic cylinder with spherical ends, and supported by a rod of glass. Attached to its lower surface, at intervals, are pairs of pith-ball pendulums, supported by threads of some conducting substance.

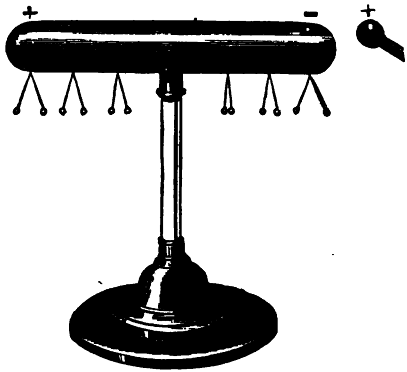

Fig. 343.

When the cylinder is brought slowly towards the electrical machine, we see the pith balls repel each other and diverge. This divergence is unequal at different points, being greatest near the extremities of the cylinder; towards the middle of the cylinder the pith balls remain in contact without repelling each other. We conclude from these facts that the *electricities* are driven towards the extremities of the cylinder, while the central portion remains in a neutral state, thus showing *polarity* as in the action of a magnet on soft iron.

If a stick of resin be rubbed with silk and brought near the pith balls towards the electrical machine, they will be repelled, showing that that end of the cylinder is negatively electrified. If it is brought near the pith balls at the remote extremity of the cylinder, they are attracted, showing that that end of the cylinder is positively electrified. Finally, the electricities in the two ends are equal in quantity, as may be shown by removing the cylinder, when they neutralize each other.

The positive electricity of the machine, then, simply acts to separate the two fluids, attracting the negative fluid to the end nearest it, and repelling the positive fluid to the opposite end of the cylinder. No electricity passes from the electrified body to the one in a neutral state when induction takes place.

498. Faraday's Theory of Induction. — FARADAY assumes in his theory that electricity polarized all the molecules of bodies and the surrounding medium. The molecules of good non-conductors *retain* their electricity, but those of good conductors discharge it from one molecule to another. Let P (Fig. 344) represent the end of the prime conductor in Fig. 343, which is charged with positive electricity, and N the end of the small conductor. The small circles between represent molecules of air, the white halves the positive sides and the black the negative.

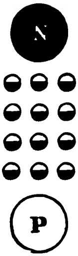

Fig. 344.

The conductor P polarizes the molecules of air next to it; these in turn polarize the succeeding ones, and so on, until all are polarized. Being non-conductors, however, they retain their electricities. When N is reached, being a conductor, there is a discharge between successive molecules, until the negative electricity collects at one end and the positive at the other.

499. The Electrophorus. — The ELECTROPHORUS is a machine due to VOLTA, by means of which we may obtain considerable quantities of electricity.

It consists of two pieces, — one a plate of resin spread on a table of wood, and the other a wooden plate covered with tin-foil, and provided with an insulating handle of glass. It is represented in Figs. 345–347.

Fig. 345.

To use this instrument, we begin by rubbing the resinous plate vigorously with a cat's skin, as shown in Fig. 345. This develops negative electricity in the resin. We then 'he disk, holding it by its handle. The plate of resin

acts upon the disk by induction, drawing the positive electricity to the tin-foil on its lower face, and repelling the negative electricity to the foil on the upper face.

In this position, if the upper face be touched with the finger, as shown in Fig. 346, the negative electricity will be drawn off into the body, and the disk will be charged with positive electricity. If the disk be raised from the resinous plate by its handle, and touched

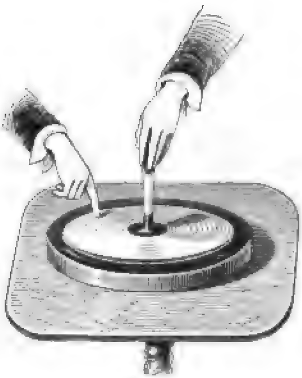

Fig. 346.

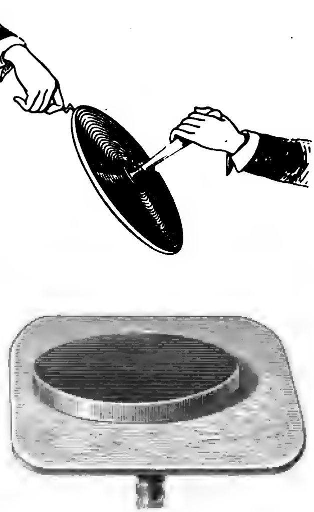

Fig. 347.

with the knuckle, as shown in Fig. 347, a spark will pass, which is due to the negative electricity passing from the body to the positively electrified plate.

If now we continue to repeat the manipulation, exhibited in Figs. 346, 347, a succession of sparks may be obtained without the necessity of rubbing the resin again with the cat's skin. If the air is dry, the resin will continue in an electrified state for a very long time.

500. The Electrical Machine. — The ELECTRICAL MACHINE is a machine by means of which an unlimited amount of electricity may be generated by friction.

This machine was invented about two hundred years ago by OTTO

VON GUERICKE, the distinguished inventor of the air-pump. The first machine was simply a ball of sulphur fixed upon a wooden axis. On turning the axis, and at the same time pressing one hand against the ball, a quantity of frictional electricity was developed.

One of the best machines for ordinary purposes is the plate machine represented in Fig. 348.

The principal piece of the machine is a *circular plate* of glass, mounted upon a horizontal axis and turned by a crank. At the right of the plate, but so constructed as to embrace a

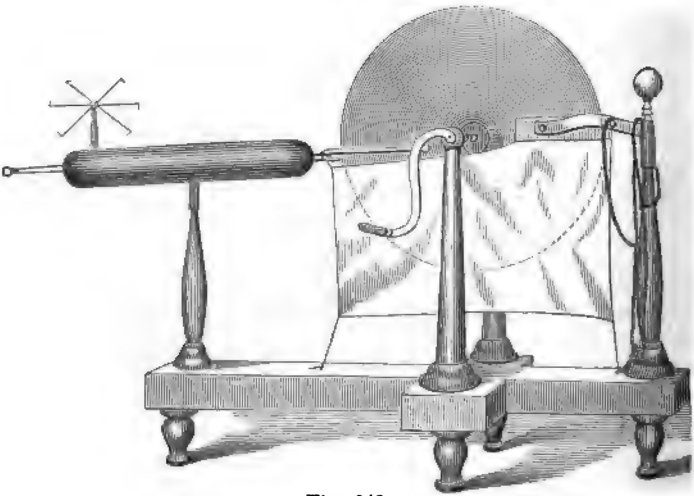

Fig. 348.

portion of it as we turn the crank, are two *rubbers*, usually of leather covered with an amalgam (a mixture of tin, zinc, and mercury) which by their friction develop electricity.

The brass cylinder in front of the plate is called the *prime conductor*; it is insulated by a glass standard to prevent the electricity from escaping to the earth. At the end of the conductor nearest the plate is a piece called a comb, from the fact that a great number of projecting teeth are placed on its side next the plate, but not to touch it.

The silk bag serves to keep the electricity on the plate.

The negative conductor is the brass sphere at the right insulated by a glass standard.

Finally, all of the ends of the cylinders in the machine are wrought into spherical forms, to prevent the dissipation of electricity as much as possible.

501. Use of the Electrical Machine. — When the plate is turned rapidly, the friction of the rubbers develops a great quantity of positive electricity on the glass, and negative on the rubbers, which is conveyed along the chain to the earth, and thus disappears.

The positive electricity on the plate acts by induction on the prime conductor, attracting its negative electricity. This collects on the teeth of the combs, and neutralizes the positive on the glass plate. The prime conductor, thus having given up its negative, remains charged with positive electricity.

When we want negative electricity we can take the chain from the rubbers and place it on the prime conductor. The electricity will then collect on the negative conductor.

If both conductors are insulated there is very little electrical action, as the two electricities hold each other in check. The plate gives up no electricity to the prime conductor; it only attracts its negative.

502. Holtz's Electrical Machine. — The HOLTZ machine is based on the principle of *continuous induction*. It consists of two circular glass plates (Fig. 349), about one tenth of an inch apart. The larger one, *A*, is fixed and insulated, but the smaller one, *B*, can be made to revolve very near it. In *A* are two openings, or windows. Across these and partly covering them on the back of the plate, *A*, are glued two varnished papers, or armatures, with tongues, *f f′*, which project into the windows. Two metallic combs, *P P′*, are placed in front of the armatures, on the other side of the plate, *B*. These combs are connected by insulated conductors with the knobs *m n*, which may be called the *poles* of the machine.

The distance between the knobs is regulated by the sliding rod attached to the knob, *m*, which has a wooden handle.

In operating the machine the two knobs are first brought together; one of the armatures, *f*, for instance, is negatively charged by holding against it a piece of vulcanite, which has previously been excited by rubbing it on a cat's skin; *f* then induces positive electricity on the face of *B* next to it, and negative on the opposite face. The latter attracts the positive from the comb, *P*, together with that of the conductor and

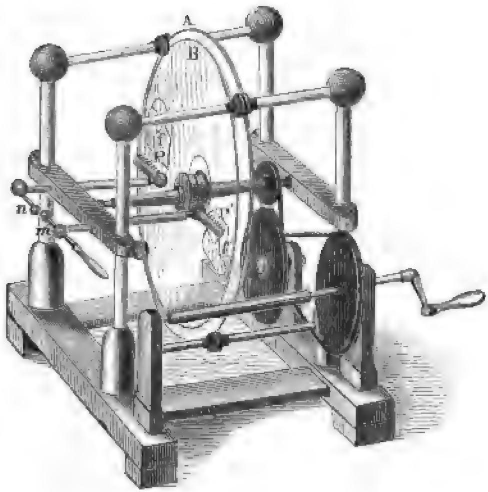

Fig. 349.

knob, *n*, and leaves them charged negatively. The tongue, *f*, facilitates the passage of electricity.

When we turn the plate, *B*, which is now charged with positive electricity, and bring it opposite the armature, *f′*, induction again takes place, the positive glass attracts negative electricity from *f′*, leaving it positively charged, at the same time negative electricity is drawn through the comb, *P′*, leaving *m* positively charged.

After the plate is turned a few seconds, the charges of the knobs and armatures are strengthened, and the two knobs, *n* being the negative pole and *m* the positive, are then gradually

separated. A torrent of sparks will pass between the two knobs. If we connect one of the poles with the ground by a chain, the other may be used as a prime conductor.

This machine is very much affected by the moisture of the air, although its power is very much greater than the plate machine, the length of the spark being nearly equal to the radius of the revolving plate.

503. **Carré's Dielectric Machine** has much to recommend it. It is a combination of the Holtz and the plate machine. Its power is greater than the plate, but much less than the Holtz. Moisture in the air affects it about the same as the plate, but less than the Holtz machine.

Besides these methods for producing electricity, many other arrangements have been devised. The *hydro-electric* machine generates electricity by causing steam charged with vesicles of water to issue forth from jets attached to a steam-boiler. The friction of these globules of water against the surface of the jets generates the electricity.

504. **Precautions in using the Machine.**—After the prime conductor is electrified, if we cease to turn the plate, and the air is dry, a pith ball attached to the prime conductor will descend slowly, showing a gradual dispersion of the electricity. If the air is damp, the ball descends rapidly, showing a rapid loss of electricity. Electrical experiments seldom succeed in a damp day. In order that they should be successful, the instrument, as well as the surrounding atmosphere, ought to be perfectly dry.

Only a certain amount of electricity can be retained on the prime conductor, after which, if the plate is turned, the tension becomes so great that it escapes through the earth or along the glass legs of the conductor, and all that is generated continues thenceforth to be dissipated. The pith ball indicates that the instrument is fully charged by ceasing to rise, and remaining stationary as the plate is turned.

505. **Electrical Condenser.**—An ELECTRICAL CONDENSER is an apparatus employed for the accumulation of electricity. They are of various forms, but are all essentially composed of two conductors, separated by an insulator.

One of the simplest and most convenient forms is the Leyden jar, which will be described in the following article.

506. The Leyden Jar is named from the city where it was invented. In its improved form it consists of a bottle or jar of thin glass, as shown in Fig. 350, nearly covered on its outside and inside with tin-foil. A wire passing through a cover of varnished wood extends to the inner coating of tin-foil, and terminates externally in a sphere of metal called the *button*.

The Leyden jar is charged by holding the outer tinned part in the hand, and bringing the button in contact with the prime conductor of an electrical machine. The positive electricity is accumulated in the interior, and acts by induction upon the outer coating, which becomes negative, the positive electricity in that coating being conveyed away by the hand through the body. As in the condenser, the two forces react so as to accumulate a large quantity of positive electricity on the inside of the jar, and of negative electricity on the outside.

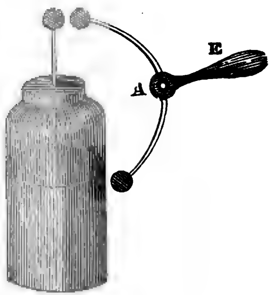

Fig. 350.

After the jar has been charged, if it be held in one hand while the other is brought in contact with the button, a sensation will be felt through the arms and body, called the electric shock, and the jar will return to its neutral state. When it is desirable to discharge the jar without the shock, the discharger is used, as shown in Fig. 350. One ball of the discharger is made to touch the outer coating, and the other is then brought in contact with the button. In this case there is a spark emitted, and the jar returns to its neutral condition.

507. Electrical Battery. — An ELECTRICAL BATTERY consists of an assemblage of Leyden jars, so connected as to act like a single condenser, as shown in Fig. 351. The jars are placed in a box whose bottom is lined with metal, which

serves to connect their outside surfaces. Their inside surfaces are brought into communication by connecting the several buttons with metallic rods.

In batteries the jars are made large, and are covered within and without with tin-foil, the interior lining being brought into communication with the button of each jar by a metallic chain. Upon one

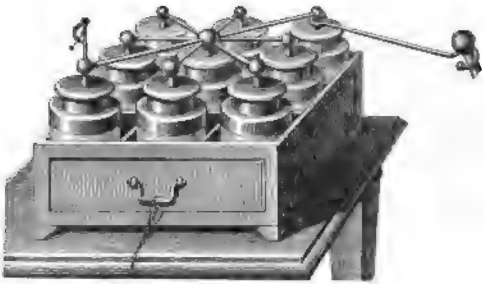

Fig. 351.

of the buttons is placed an electrical pendulum, which indicates the excess of the fluid on the inner over that on the outer surface.

The battery is charged by attaching a bar, a portion of which is seen in the figure, or chain to the knob of one of the jars, and also to the prime conductor.

508. Leyden Jar with Movable Coatings. — The tin-foil coatings of the Leyden jar act merely as conductors, and the opposite electricities reside chiefly on the opposite surfaces of the glass. Fig. 352 represents a jar with movable coatings. When the jar is charged it is placed on an insulating stand.

The pieces are taken apart, as shown in the figure, and the two coatings are found to contain little or no electricity. But when the parts are put together again, a charge may be received from it almost as great as it would have given if the coatings had not been removed.

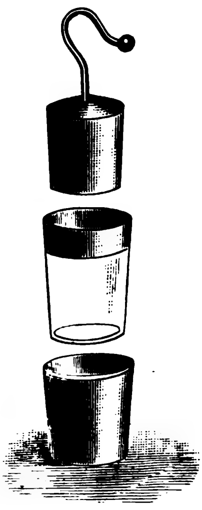

Fig. 352.

Summary. —

Induction.

Definition.

Illustrated by Figure.

Faraday's Theory.

Illustrated by Figure.

Electrophorus.

Description and Figure.

Method of Using it.

Electrical Machine.

By whom Invented.

Description of Plate Machine.

Method of using the Plate Machine.

Description of Holtz's Machine.

Method of using the Holtz Machine.

Carré's Dielectric Machine.

Power compared with that of the Plate and Holtz Machines.

The Hydro-electric Machine.

Precautions in using Electrical Machines.

Dispersion of Electricity by Dampness.

Escape of Electricity after the Machine is fully charged.

Electrical Condenser.

Definition.

Description of the Leyden Jar.

Method of Charging and Discharging it.

Description of Electrical Battery.

Leyden Jar with Movable Coatings.

Explained by Figure.

SECTION III. — EXPERIMENTS WITH THE ELECTRIC MACHINE.

509. Electrical Spark. — Electrical Shock. — An ELECTRICAL SPARK is a brilliant flash of light which passes when a conductor approaches a highly electrified body.

The spark produced in discharging the Leyden jar, and the

shock felt by the experimenter when it is done with the hands, were described in treating of electrical condensers. A similar spark, but not so brilliant, can be drawn from the prime conductor of an electric machine when the finger is presented to it. A shock will also be felt, but not so violent as that from the jar. It is a sharp, prickly sensation.

The spark arises from the combination of the two opposite electricities. The positive electricity, acting at a distance by induction, drives the positive electricity of the hand to the earth, and attracts the negative; consequently the body of the experimenter becomes negatively electrified. When the tensions of the positive electricity of the machine and the negative electricity of the body overcome the resistance of the air, they rush together with a sharp crack and a bright light which constitutes the spark. When the electrical machine is powerful, the sparks take a zigzag course, like lightning from a storm-cloud.

510. The Electrical Stool. — A spark may be drawn from the human body when properly electrified. For this purpose an ELECTRICAL STOOL, that is, a stool insulated by means of glass legs, is used. A person standing on the stool, and taking hold of the prime conductor, becomes, when the plate is turned, positively electrified. If a second person now attempts to shake hands with the first, a shock will be experienced, and a spark will pass between them.

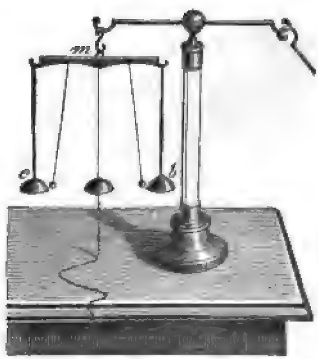

Fig. 353.

511. The Electrical Chime is a collection of bells that are made to ring by means of electrical attractions and repulsions.

It consists, in the case shown in Fig. 353, of three bells suspended from a horizontal bar of wood, *m*. The

outer bells, *b* and *c*, are suspended by metallic chains, and the middle one by a silk cord; the middle bell, moreover, is connected with the earth by means of a metallic chain. Between the bells are two balls of metal, suspended from the bar, *m*, by a cord of silk. The entire apparatus is connected with the prime conductor of an electrical machine by means of the rod at the right of the figure.

When the machine is turned, the outer bells become positively electrified, and attract the balls, which impinge against them, become electrified, and are immediately repelled, striking against the middle bell, where they lose their charge, and are again attracted to the extreme bells, and again repelled. This alternate attraction and repulsion of the balls keeps up the ringing as long as the plate is turned.

512. The Electrical Image consists of a little figure which is made to dance by means of electrical attraction and repulsion.

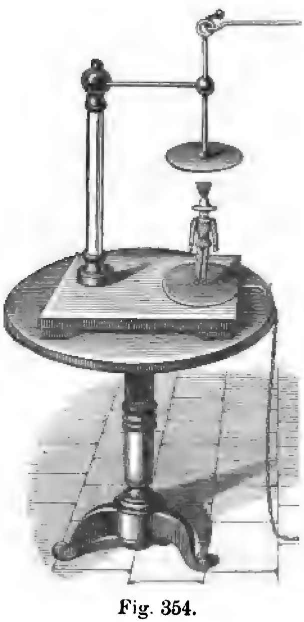

Fig. 354.

It consists of a light image, made of elder pith, or some similar substance, placed between two metallic plates, one of which is in connection with the prime conductor of the machine, and the other with the earth by means of a chain, as shown in Fig. 354.

When the machine is turned, the upper plate is positively electrified, and attracts the image to it. The image is charged and immediately repelled to the lower plate, where it loses its electricity, and is again attracted to the upper plate, and so on, dancing up and down as long as the plate is turned.

513. The Effect of Points in Electrical Action. — The accumulation of electricity at points gives rise to a high tension, which is sufficient to overcome the resistance of the air and to give rise to an escaping current. In fact, metallic bodies of a pointed shape soon lose the electricity imparted to them, and often the escaping current may be felt by placing the hand in front of the point. If a candle-flame is held near the point, it will be blown away from it. If the flow takes place in a darkened room, it may be discovered by a feathery jet of faint light.

The current is formed by the repulsion of the electrified air in the vicinity of the point. The molecules are polarized, give up electricity opposite to that with which the point is charged, which unites

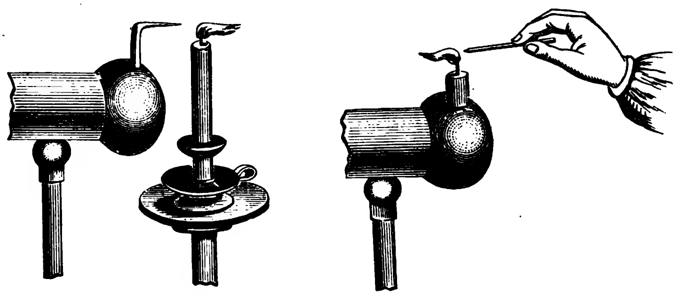

Fig. 355.

with the electricity of the point to neutralize it, and consequently, becoming themselves charged with the same kind as the point, are repelled, and new ones take their places; hence the current.

In working an electric machine, all objects with points, as angular objects, should be avoided. The prime conductor tends to abstract from surrounding objects their negative electricity, and to return to its neutral condition.

The effect of neighboring bodies may be illustrated by bringing a metallic point near a charged prime conductor. When the point is at a considerable distance from the conductor, the pith ball on the prime conductor begins to fall, showing a loss of electricity.

It is sometimes said that the point draws off the electricity from the conductor, but this is not the case; the point abstracts none of

the positive electricity, but gives to the conductor negative electricity, which unites with the positive to neutralize it.

If a candle is placed on a prime conductor, and a metallic point held near it, the flame will be blown away from it. The current arises in this case from the flow of air charged with contrary electricity, to neutralize the electricity of the conductor.

These effects of points are illustrated in Fig. 355.

514. The Electrical Wheel consists of several arms, bent in the same direction, and attached to a small cap which is free to rotate about a pivot.

This pivot is attached to the prime conductor, or else to a metallic support, connected with the conductor. Fig. 356 represents such a wheel. It is a reaction wheel, and is made to turn by the escape of electricity from the points.

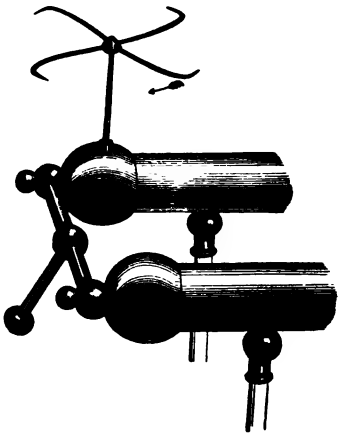

Fig. 356.

When the plate of the machine is turned, the prime conductor and the wheel become electrified; the tension of the electricity at the points becomes very great, and finally escapes with a force that causes the wheel to revolve in a direction indicated by the arrow-head, that is, in a direction contrary to that in which the points are bent. The wheel does not turn in a vacuum, which shows that electricity escapes from points in a vacuum without resistance.

515. Velocity of Electricity. — Duration of the Spark. — The velocity of electricity is immense, much greater than that of light. It has been determined that the velocity of the electrical discharge through copper wire is more than 288,000 miles per second.

The velocity varies, however, with its intensity, and the medium through which it passes.

The duration of the electric spark is exceedingly brief. If we divide a circle into black and white sectors (Fig. 357), and then cause it to rotate so rapidly that the sectors blend into a uniform gray, if the room be darkened and the circle illuminated by a spark from the Leyden jar, it will appear perfectly still, and every individual sector will be distinctly seen.

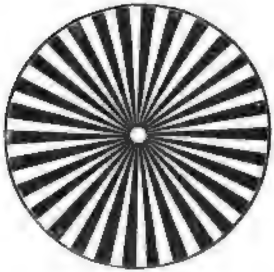

Fig. 357.

516. The Electrical Egg is an egg-shaped light, produced by the passage of electricity through a vacuum.

The method of exhibiting this light, and the apparatus employed, are shown in Fig. 358. The apparatus consists of a hollow globe or oval of glass, containing two small metallic spheres at some distance apart. The upper one communicates with the prime conductor, and the lower one with the earth.

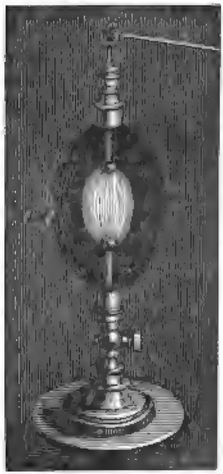

Fig. 358.

The globe may be deprived of its internal air by means of the air-pump. Then, if the plate of the machine be turned, electricity will escape from the machine to the earth through the two balls, and because the balls are in a vacuum there will be no obstruction to its passage. If the experiment is made in a darkened room, a beautiful violet-colored light will be seen between the two balls, of the shape shown in the figure.

517. The Electrical Square consists of a square plate of glass, upon one surface of which a thin strip of tin-foil is fastened, running backwards and forwards across the plate, as shown by the black line in Fig. 359. One end of this

strip of tin is made to connect with the prime conductor of the electrical machine, and the other end is made to communicate with the earth by a chain. The square is insulated by legs of glass.

Fig. 359.

When the plate is turned, a current of electricity flows through the strip of tin from the machine to the earth, and no spark is given out. If, however, the tin is broken at any point, there will be a succession of sparks at that point, which will be so close together as to produce a continuous light. If, now, the tin be broken by a penknife, so that the points of rupture are arranged in a definite figure, as that of a flower, for instance, a continuous light will be seen at each of these points, and the figure will appear as if traced upon the glass with fire. Any kind of figure may be drawn, or words may be written on the glass.

The experiment is more striking in a darkened room.

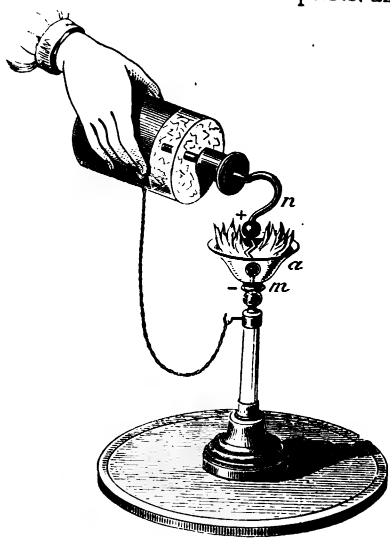

Fig. 360.

518. Heating Power of Electricity. — The heat developed by electricity is sufficient not only to inflame ether, gunpowder, coal-gas, and the like, but also to melt and volatilize the metals.

Fig. 360 represents the manner of inflaming ether. It is poured

into a glass vase, through the bottom of which passes a metallic wire terminating in a button. The wire is connected by a chain with the outer covering of a Leyden jar. When the circuit is completed by touching the button of the apparatus with that of the jar, a spark is given off, and heat enough developed to inflame the ether.

This experiment succeeds with a very small jar, or even a simple spark from the prime conductor. The experiment may be made more interesting by standing upon the electrical stool, and inflaming the ether with the finger. The ether may be inflamed by a spark from a piece of ice held in the hand.

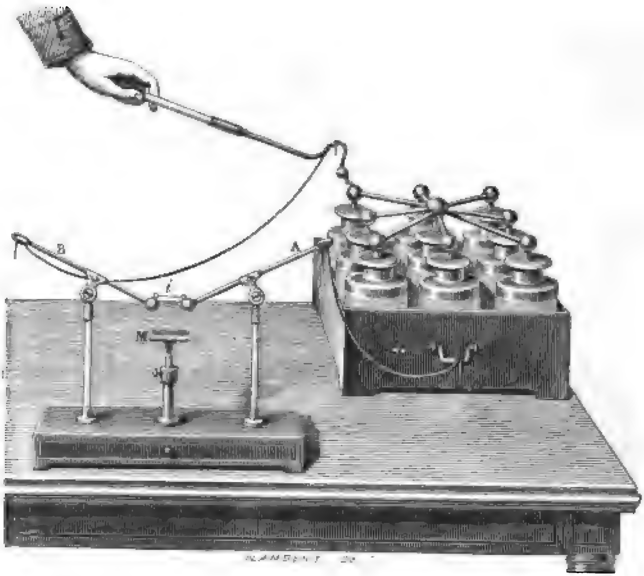

Fig. 361.

When an electrical battery is discharged through a fine metallic wire, it may be melted or even volatilized, according to the power of the battery.

In performing this experiment it will be best to use the *universal discharger*. This instrument and the manner of using it are shown in Fig. 361. The discharger consists of two copper wires, *A* and *B*,

mounted upon glass supports. The wires can slide freely through the rings that hold them, and can furthermore be turned about hinge-joints, so as to bring their buttons as near as may be desired to any body that is placed upon the stand, *M*.

To melt a wire by electricity, we attach it to the two inner buttons at *i*, then connect one of the wires, *A*, for example, with the exterior coating of the battery, and complete the circuit by connecting *B* with the button of one of the jars of the battery. This is effected in the manner shown in the figure, the connecting chain being managed by means of a hook with a glass handle. At the instant of contact, the wire, if fine enough, is melted into globules, and even volatilized. that is, reduced to vapor, which disappears in the air.

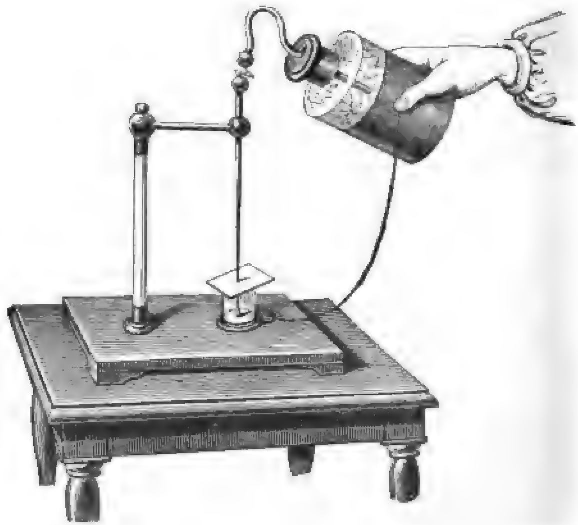

Fig. 362.

When the wire is a little larger, it simply becomes red-hot and gives forth a brilliant light; if still larger, it becomes heated without being luminous. Fine and short wires may be melted under water in the same manner as in air, but the experiment is more difficult to make.

519. Mechanical Effects of Electricity. — The MECHANICAL EFFECTS OF ELECTRICITY are manifested when large charges of electricity are passed through imperfect con-

ductors. They consist of violent expansions, with tearing, fracturing, and the like.

These effects are generally exhibited by placing the body upon the plate, *M*, of the universal discharger (Fig. 361), and then passing a powerful charge from a battery through it. In this way a small block of wood may be torn to splinters in an instant.

Fig. 362 represents an apparatus by means of which a hole may be torn in a card by using a single Leyden jar. A card is placed at the top of a glass cylinder, beneath which is a wire projecting from a metallic plate. The plate connects by a chain with the exterior coating of the jar. Above the card is a second wire, which is insulated in the manner shown in the figure. When the circuit is completed, by touching the upper wire with the button of the jar, a shock follows, and the card is found to have been pierced as if run through by a needle or pin.

520. Chemical Effects of Electricity. — The electric spark is capable of producing chemical reactions. For example, water is formed of oxygen and hydrogen gases, in the proportion of one volume of the former to two volumes of the latter. Now, if these two gases be mixed in this proportion, and an electrical spark be passed through the mixture, the gases instantly unite and form water. Moreover, the combination takes place with a brilliant flash of light and a loud report, the report being due to the expansive force of the vapor which is produced at the moment of combination. It is upon these principles that the electrical pistol represented in Fig. 363 is constructed.

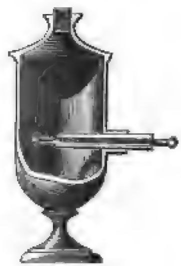

Fig. 363.

Nitric acid is formed by the passage of electric sparks through moist air.

Sulphuretted hydrogen, ammonia, and carbonic acid are decomposed by the electric spark.

The chemical effects of frictional electricity are not so powerful or varied as those of dynamical, which will be considered under that subject.

521. Physiological Effects of Electricity. — The Physiological Effects of Electricity are the effects which

it produces on men and animals. They consist of muscular contractions, accompanied by a greater or less amount of pain, according to the power of the electrical apparatus.

When we receive a simple spark from the prime conductor, we experience only a slight stinging sensation; with a small Leyden jar, the pain is felt extending up the arms to the elbows or shoulders; with a more powerful jar or a battery, the shock is felt through the arms and chest, and may be sufficient to produce death.

An electric shock may be given to a great number of persons at the same time. To that end they form a chain by taking each other by the hand; then the person at one end takes a Leyden jar in his hand: the circuit is completed by the person at the other end of the chain touching the button of the jar, when the shock is felt simultaneously throughout the ring. NOLLET administered in this manner, in the presence of LOUIS XV., an electrical shock to an entire regiment of fifteen hundred men.

With a battery, the shock becomes so powerful as to render it dangerous to attempt receiving it. With a battery of only six jars of mean size, it would be hazardous to receive the shock. With more powerful batteries, cats, dogs, and even stronger animals may be killed by a single shock.

We shall find, further on, that electricity in its dynamical form is used in the treatment of diseases.

Summary. —

Electrical Spark and Shock.

How the Spark is produced.
When a Shock is experienced.
Formation of the Spark.

The Electrical Stool.

Method of Using it.

The Electrical Chime.

Action explained and illustrated by Figure.

The Electrical Image.

Action explained and illustrated by Figure.

Effects of Points in Electrical Action.

Electricity escaping from Points on an Electrified Body.
Theory of the Current formed in this Way.

Effect of Points in Electrical Action (continued).
Loss of Electricity from the Prime Conductor when near Pointed Objects.
Current formed.
Action of Points on a Flame illustrated by Figure.
Rotation of the Electric Wheel explained.
Velocity of Electricity. — Duration of the Spark.
Velocity through Copper Wire.
Duration of Spark illustrated by Figure.
The Electrical Egg.
Method of producing this Light explained by Figure.
The Electrical Square.
Method of illuminating the Square explained by Figure.
Heating Power of Electricity.
Illustrated with the Leyden Jar and Ether.
Illustrated with Battery and Wire.
Mechanical Effects of Electricity.
Shown by the Battery and Block.
Shown by the Leyden Jar and Card.
Chemical Effects of Electricity.
In combining Oxygen and Hydrogen by the Electrical Pistol.
In decomposing certain Compounds.
Physiological Effects of Electricity.
Illustrations.

SECTION IV. — ATMOSPHERIC ELECTRICITY.

522. Identity of Lightning and the Electric Spark. — The complete identity between lightning and electricity was established by Dr. FRANKLIN, at Philadelphia, in 1752. He raised a silken kite, provided with a metallic point, just before a coming thunder-storm. The string of the kite was of hemp; attached to the lower end of it was a small key, and fastened to the key was a silken cord, by which the kite might be insulated. It was only after the string became damp from the falling rain that the key showed signs of being

electrified. He was at last rewarded by obtaining an electric spark.

523. **Atmospheric Electricity.** — The existence of atmospheric electricity is not confined to clouds alone, for it often exists in the atmosphere when no trace of a cloud is visible. In this case the electricity is positive. It is most abundant in open spaces and at considerable elevations. In houses, in the streets, under trees, and in sheltered localities, no trace of free electricity is discoverable. During storms the electricity of the air is sometimes positive and sometimes negative. All clouds are supposed to be electrified, some positively and some negatively.

The electrical condition of clouds may be determined by metallic rods, by kites, or by small balloons held by a string in the hand.

The electrical state of the atmosphere may be determined in a great variety of ways. Sometimes the gold-leaf electroscope is used. Instead of the button there is a stem of metal, and a fine and flexible wire attached to its upper end. To the second extremity of the wire is fastened an arrow, which, being shot from a bow, ascends into the atmosphere, drawing the wire with it. When the arrow is shot directly upwards, the divergence of the gold leaves indicates the existence of free electricity, and the nature of this electricity is tested as already explained.

524. **Causes of Atmospheric Electricity.** — The origin of the electricity of the atmosphere is imperfectly understood. Many theories have been brought forward to explain it. The following are generally supposed to be some of the causes that contribute to its development: friction of the air, evaporation and condensation of water, vegetation, and combustion.

525. **Lightning** is nothing else than an elongated electrical spark, which passes between two differently electrified clouds when brought near each other. Sometimes a discharge takes place between a cloud and the earth. It is the recombination of the opposite electricities.

A flash of lightning is often of great length, and as it takes place along the line of least resistance, it generally follows a zigzag path, as is often the case with the spark from a Leyden jar. When we see its entire length we call it *chain-lightning.* When a flash of lightning is seen in the lower regions of the atmosphere, it has a brilliant white color; but in the higher regions, where the air is rarefied, it assumes a violet hue, similar to that of the electric egg (Art. 516).

Sheet-lightning is that which flashes through the clouds, causing extensive illumination.

Heat-lightning is supposed to be the reflection of the lightning of distant storms.

526. **Thunder** is the sound which follows a flash of lightning. It is due to vibrations caused by the passage of the spark through the air, and the clashing together of the molecules of air in filling the vacuum caused by the lightning.

Thunder is not heard till an appreciable time after the flash is perceived. This arises from the fact that light travels with immense velocity, reaching the eye instantaneously, while sound travels more slowly, and reaches the ear only after a sensible interval of time. The distance of a clap of thunder may be ascertained by counting the number of seconds between the flash and the report, and allowing five seconds to a mile.

The intensity of the sound diminishes as the distance becomes greater: near by, it is sharp and rattling, like boards falling one upon the other; at a greater distance, it is dull, and prolonged in a low rumble of varying intensities.

The rattling or rolling of thunder is differently explained. By some it is said to be due to a succession of echoes from the clouds and the earth. Others regard lightning, not as a single spark, but as a succession of sparks, each giving rise to separate explosions that succeed each other so rapidly as to produce a continuous rumbling sound. Others again attribute the rolling of thunder to the zigzag course of the lightning, the sound from different points of the zigzag path reaching the ear in times proportional to their distances. In this way the sounds from different points are superposed irregularly, giving rise to irregularity in the resulting sound.

527. **Effects of Lightning.** — When an electrified cloud passes near the earth, it acts upon it by induction, repelling

the electricity of the same name and attracting that of an opposite name. As soon as the tension of the two electricities becomes greater than the resistance of the intervening air, a spark or flash passes, and a *thunderbolt* is said to *fall*, or the lightning to *strike*. The flash generally passes from the cloud to the earth, but sometimes the reverse is the case. When the lightning *ascends*, the clouds are probably negatively and the earth positively electrified, since it has been shown by experiment that at the ordinary pressure positive electricity passes through the air more easily than negative.

The attraction between the two electricities increases as the distance diminishes. Hence it is that elevated objects are most likely to be struck, such as spires, high trees, lofty buildings, and the like. Good conductors, like metals, moist bodies, trees, and the like, are more likely to be struck than bad conductors. Hence the danger of taking refuge under a tree in a thunder-storm.

The effects of the thunderbolt are extremely various and wonderful. It crushes or fractures bad conductors, inflames combustible bodies, melts metals, reverses the poles of magnets, and often kills men and animals. Sometimes it falls slowly in the form of a globe of fire, and then explodes with a noise like a battery of cannon. It is this form of lightning that is most likely to inflame the edifices which it chances to strike.

528. **The Return Shock** is a violent, and sometimes fatal shock, felt by men and animals even at a great distance from the place where the lightning strikes.

This phenomenon is due to the inductive influence exerted by an electrified cloud upon bodies beneath it, which are all strongly charged with electricity contrary to that of the cloud. Now, if a discharge takes place at any point, the cloud returns to its neutral state, induction ceases instantly, and all of the bodies electrified by induction instantly return to a neutral state. The suddenness of this return is what constitutes the return shock.

The return shock may be illustrated on a small scale by placing a living frog near an electrical machine in motion. Every time that the machine is discharged by placing the finger upon it, the frog experiences a shock, which is nothing else than the return shock above ibed.

529. Lightning-Rods. — A LIGHTNING-ROD is a rod of metal, placed upon a building or ship to preserve it from the effect of lightning. Galvanized iron or copper is now generally used.

A lightning-rod should fulfil the following conditions: —

1. It should be of sufficient size so as not to be melted while carrying the charge off.

A copper rod of half an inch in diameter, or an iron one of three fourths of an inch in diameter, is large enough to protect any building.

2. They should be of one piece throughout.

3. They should terminate in points to give readier egress for the electricity that is set free by induction.

4. The rod should be carried down into the earth till it meets with a good conducting medium, such as a layer of wet or moist earth.

When no such medium can be reached, a pit should be dug, and after the lower end of the rod has been carried to the bottom, it should be nearly filled with some good conductor, as coke. This will also prevent rusting.

A rod is supposed to protect a circular space about it, whose radius is about twice the length of that portion of the rod that extends above the building. The lightning-rod was invented by FRANKLIN, who thought that its protective action consisted in drawing off the electricity from the cloud, and conducting it to the earth.

The real explanation of its utility is just the reverse. The cloud acts by induction upon the earth, repelling the electricity of the same name as that in the cloud, and attracting that of an opposite name, which accumulates upon the bodies under the cloud. Now, by arming a body with metallic points communicating with the earth, we permit a passage of electricity from the earth to the cloud. This not only prevents the accumulation of electricity upon the body, but it tends gradually to neutralize the electricity of the cloud itself, and thus the rod acts in a double way to prevent the body from being struck.

When the electricity set free is more than the conductor can discharge the lightning strikes, but the rod receives the discharge, owing to its higher conducting power, and protects the building.

530. The Aurora Borealis. — The AURORA is a luminous phenomenon, which appears most frequently about the poles of the earth, and more particularly about the *boreal* or northern pole, whence its name.

At the close of twilight a vague and dim light appears in the horizon in the direction of the magnetic meridian. This light gradually assumes the form of an arch of a pale yellowish color, having its concave side turned towards the earth. From this arch streams of

Fig. 364.

light shoot forth, passing from yellow to pale green, and then to the most brilliant violet purple. These rays or streams of light generally converge to that point of the heavens which is indicated by the dipping needle, and they then appear to form a fragment of an immense cupola, as shown in Fig. 364.

Since the aurora is always accompanied by a disturbance of the magnetic needle, and is generally arranged in the direction of the dip, and acts upon telegraph wires, it is inferred that it is due to electrical action. Such is at present the generally received belief.

Summary. —

Identity of Lightning and the Electric Spark.
- Discovered by Dr. Franklin.
- Method of its Discovery.

Atmospheric Electricity.
- Found in the Clouds and in the Atmosphere when free from Clouds.
- Method of determining the Electrical Condition of Clouds.

Causes of Atmospheric Electricity.
- Friction of the Air.
- Evaporation and Condensation of Water.
- Vegetation.
- Combustion.

Lightning.
- Definition.
- Different Kinds.

Thunder.
- Definition.
- Method of ascertaining the Distance of Thunder.
- Rolling of Thunder explained.

Effects of Lightning.
- Why Lightning strikes.
- Examples of the Destructive Effects of Lightning.

The Return Shock.
- Definition and Cause.
- Experiment with Frog.

Lightning-Rods.
- Definition.
- Conditions of a Good Rod.
- Explanation of the Action of a Lightning-Rod.

The Aurora Borealis.
- Definition.
- Illustrated by Figure.

ELECTRICITY.

Part III. — DYNAMICAL ELECTRICITY.

SECTION I. — FUNDAMENTAL PRINCIPLES.

531. Galvani's Experiment. — It has been observed that chemical combinations are sources of electricity. The form of electricity thus developed is different, but its nature is the same as that produced by friction; but inasmuch as its manifestations of power are continuous from the very moment of its production, it is called *dynamical electricity*, the word *dynamical* being derived from a Greek word meaning power. The name of GALVANISM has been given to electricity developed by certain chemical combinations, in honor of GALVANI, who first discovered this new way of generating it. It is also called Voltaic electricity, from VOLTA, who added to the discoveries of GALVANI.

GALVANI observed one day that a dead frog, which was suspended from a copper hook in a window, exhibited muscular contractions whenever the wind blew the lower extremities against the iron bars of the window. Here was a case of electrical manifestation which furnished a clew to one of the most important discoveries of modern science.

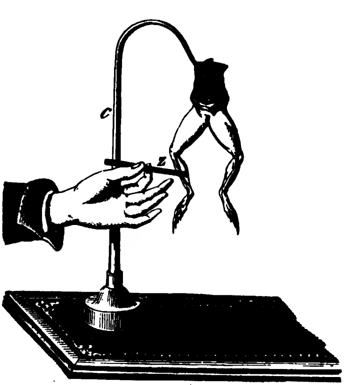

Fig. 365.

This discovery led to an experiment which may be repeated as follows: Having killed a frog and cut off the hinder half of the body, we suspend it by a copper hook, *c*, passed between the backbone and the nerves which run on each side of it, as shown in Fig. 365; then holding a small plate of zinc, *z*, in the hand, we bring one end of it in contact with the copper stem that holds the hook, and

then touch the legs of the frog with the other end. At every contact the muscles contract, reproducing all the motions of life.

GALVANI attributed the phenomena observed to the electricity existing in animal tissues, which, passing from the nerves to the muscles, through the metals, produced the muscular contractions.

532. **Volta's Theory of Contact.** — VOLTA repeated the experiment of GALVANI, and after much study advanced the theory of contact. According to this theory, when two metals or other dissimilar substances are simply brought in contact, there is always a decomposition of the natural electricity of both bodies, the positive electricity going to one and the negative to the other.

In the case of the frog the electricity was supposed to be developed by the contact of the copper hook and zinc plate, the nerves and muscles serving simply as conductors.

533. **Fabroni's Chemical Theory.** — FABRONI first suggested that the phenomena of the pile (Art. 540) were due to chemical action. He observed that zinc became oxidized in contact with water containing acid when joined with copper, and thought that this oxidation was the principal cause of the electric action.

It seems now to be generally accepted that the separation of the electricities is caused by the contact of two different metals, but that the constant supply of electricity is kept up by chemical action.

534. **Current Electricity.** — If a plate of zinc, Z, and one of copper, C, be placed in a mixture of water and weak sulphuric acid (Fig. 366), a slight chemical change takes place in the case of the zinc, and bubbles of hydrogen gas will collect on its surface and escape to the surface of the liquid. The zinc will gradually waste away. Connect the plates with a metallic wire. The chemical action is more violent; the zinc wastes away more rapidly than before; a greater amount of hydrogen is set free, but it is disengaged at the surface of the copper instead of the zinc. Electrical action is now manifest. This apparatus is called a *simple voltaic element*, or *couple.*

If we separate the wires no such action is observed, but on being brought near each other in the dark, a small spark is seen to pass between them, which arises from the recombination of the two electricities. The passage of the spark does not discharge the plates, as in the Leyden jar. We see a continual succession of sparks, showing that the process of chemical decomposition is continually kept up in the liquid, and a constant supply of electricity furnished.

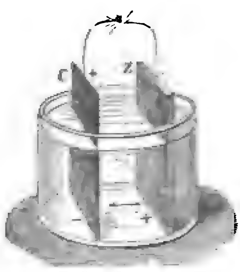

Fig. 366.

Since these electrical manifestations traverse the whole length of the wires when in contact, the name *electric current* is given them.

It is not to be supposed that in using the term *current* we mean any actual transfer of material particles. There is merely a transfer of force from molecule to molecule, the molecules of the conductor becoming polarized and charged one after the other, and thus discharging this electric force into adjacent molecules. We may consider, then, the current as due to a series of charges and discharges among the molecules in the wire of such rapid succession as to give the appearance of one uninterrupted discharge.

535. Direction of the Current. — Although there are two currents flowing in opposite directions, the positive and negative, yet, to avoid confusion, whenever the term *current* is used only the *positive* is meant.

It will be observed, in Fig. 366, that the positive current passes through the liquid from the zinc to the copper, and above the surface of the liquid from the copper to the zinc, the negative going in the opposite direction, as stated before.

The metal that is acted on the most strongly by the liquid is called the *generating*, or *positive* plate; the other the *conducting*, or *negative* plate. In such a case the former is said to be *electro-positive* towards the latter, and the latter *electro-negative* towards the former.

In Fig. 366 the zinc is electro-positive, and the copper, which is merely a conductor, and not acted on by the liquid, electro-negative. The electrical force generated by this action of the metals is called the *electromotive* force.

536. Action of the Acid. — Amalgamation of the Zinc. — If zinc is placed in water, it decomposes it, forming zinc oxide, and setting the hydrogen free. This action does not last long, as the zinc becomes coated with a film of the oxide, which is insoluble. The sulphuric acid, however, seizes the oxide of zinc, and forms sulphate of zinc, which is dissolved in the liquid, thereby leaving a clear surface on the zinc.

Chemically pure zinc is not attacked by dilute sulphuric acid until the electric current begins. Commercial zinc, however, is usually impure, and is acted on rapidly by the acid, and consequently wasted. The impurities in the zinc, usually consisting of iron or lead, also cause *local* currents, and this accelerates the chemical action and wastes the zinc, without adding to the quantity of electricity in the general current that passes over the wires. To prevent this waste, the zinc in galvanic batteries is usually amalgamated, that is, rubbed over with mercury, after it has first been cleaned in dilute acid.

537. Electrodes. — Poles. — If we cut the wire connecting the two plates in the liquid (Fig. 366), positive electricity will tend to accumulate at the end of the wire attached to the copper, or negative plate, and negative on the wire connected with the zinc, or positive plate. These ends are called the poles of the battery. Sometimes pieces of platinum are attached to the ends of the wires, as the ordinary metals would suffer corrosion in many experiments.

The term *electrode* is now often used instead of *pole*. Joining the two electrodes is called *closing the circuit;* separating them, *breaking the circuit.* Care must be exercised not to confound the *poles* with the *plates* of the couple. The *positive pole* is joined to the *negative plate*, and the *negative pole* to the *positive plate.*

538. Electrical Potential.—The ELECTRICAL POTENTIAL is that property of a body by means of which electricity tends to pass from it and flow to another body.

In order that water may flow there must be a difference of gravitation level, and we notice also a flow of heat when there is a difference of temperature level; and so we may say that to get a flow of electricity there must be a difference of electrical level, or, in other words,

a difference of electrical potential. Electricity, as well as water and heat, passes from a higher to a lower level. This in the case of electricity we call passing from a higher to a lower potential. The zinc and copper in the voltaic couple assume different electrical potentials, and the passage of the electricity when we join the wires, from the conductor at a higher to the one at a lower potential, constitutes the current, which is kept continuous by chemical action. The greater the difference of chemical action upon the two metals, the more powerful will be the current.

Summary. —

Dynamical Electricity.
- Why called Dynamical.
- Why called Galvanic and Voltaic.
- Galvani's Experiment.
- Galvani's Theory.
- Volta's Theory.
- Fabroni's Theory.

Current Electricity.
- Illustrated by the Simple Voltaic Element.
- Production of the Spark.
- Explanation of the Term *Current.*
- Direction of the Current explained.
- Definition of Terms.
- Action of the Acid on the Zinc.
- Amalgamation of the Zinc.
- Explanation of the Term *Electrodes.*

Electrical Potential.
- Illustrations.

539. **Voltaic Batteries.** —When several voltaic elements or couples are united so that their effects may be combined, the apparatus is called a *voltaic* or *galvanic* battery. The earliest of these arrangements was devised by VOLTA himself. His apparatus, however, from the mode of its arrangement, is generally called the *voltaic pile.*

540. **Volta's Theory of Contact.** — One of these voltaic piles is shown in Fig. 367. It consists of an assemblage of *couples*, each consisting of a disk of copper and a disk of zinc in contact, and

each couple being separated from the next by a layer of cloth moistened with dilute sulphuric acid, which acts upon the metals and the liquid in the cases already mentioned. The couples are all disposed in the same order, the zinc of each couple being always on the same side of the corresponding disk of copper. When the pile is completed there will be a disk of zinc at one end and a disk of copper at the other. A connection is made between them by means of the wires, *a* and *b*, one being attached to each of the extreme plates.

In the pile shown in Fig. 367 there are twenty couples, the copper disk being at the bottom of each couple, and the zinc one at the top.

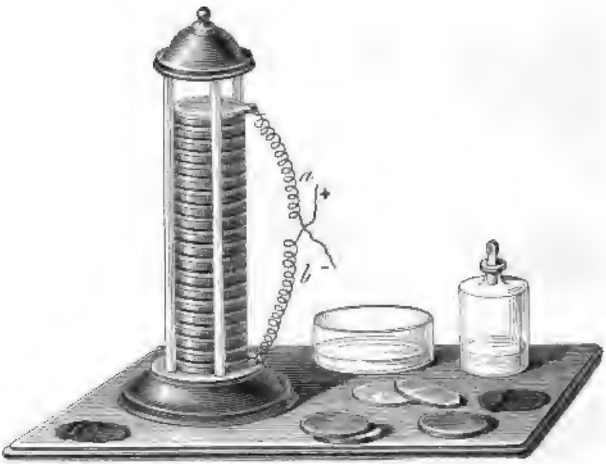

Fig. 367.

The pile is supported by a suitable framework. These disks are kept in place by glass rods.

The pile is insulated by placing it on glass or resin. The positive electrode, *a*, connects with the copper plate, and the negative, *b*, with the zinc.

541. Constant Batteries. — Batteries constructed on the principle of the voltaic couple have substantially gone out of use on account of the rapid enfeeblement of their currents. In order to secure a constant current, the permanent deposition of hydrogen on the inactive metal must be prevented, as this interferes with the current.

By putting this metal in a liquid upon which the hydrogen, as it is set free, can act chemically, this result can be secured. Many different forms of batteries have been constructed, and some of the principal ones will be described.

Fig. 368.

542. Smee's Battery. — This is a "one-fluid" battery, an element of which is represented in Fig. 368. It consists of two plates of zinc, *Z Z*, suspended in dilute sulphuric acid, *A*, by a wooden bar, *w*; between them is also suspended a plate of silver, *S*, covered with fine platinum powder. This rough surface of platinum prevents the adherence of hydrogen bubbles. In other batteries to be described the hydrogen is kept from the inactive plate by chemical action.

543. Potassium Bi-chromate Battery. — If a carbon plate be substituted for the silver one in Smee's battery, and a solution of potassium bi-chromate be put into the sulphuric acid, we shall have a potassium bi-chromate battery. A convenient form of this battery is shown in Fig. 369. The plates of carbon, two in number, are stationary, the zinc plate between can be drawn out of the solution when the battery is not in use, and thus the couple be kept without any action for weeks, and still be ready for work at a moment's notice. It is one of the very best batteries for general purposes.

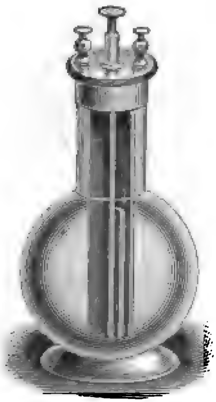

Fig. 369.

The best carbon used in batteries is gas-carbon, which forms on the inner surface of gas-retorts.

The hydrogen set free by the zinc, by taking oxygen from the water, acts chemically upon the chromic acid, so that it cannot collect on the carbon plates.

Probably one of the best solutions for this battery is the following: One gallon of water, one pound of bi-chromate of potash, and from a half-pint to a pint of sulphuric acid, according to the energy of action

desired. A small quantity of nitric acid added to the solution increases the constancy of the battery.

544. The Mercury-Sulphate Battery. — A battery, small in size but of considerable power, can be made by immersing zinc plates in a solution of sulphate of mercury contained in carbon cups. The zinc takes oxygen from the water, forming oxide of zinc; the hydrogen escapes, and decomposes the mercury sulphate into sulphuric acid and mercury. The latter amalgamates the zinc, and the sulphuric acid dissolves the zinc oxide.

545. Daniell's Battery. — This was the first form of the constant battery; in respect to the constancy of its action it is, in all probability, the best of the constant batteries. Fig. 370 represents a single couple of this battery. There is an outer vessel of glass or porcelain, filled with a solution of sulphate of copper (blue vitriol), which is kept saturated by some crystals of the sulphate placed at the bottom of the vessel. A copper cylinder is immersed in this, perforated with holes. Inside this cylinder is a thin porous vessel of unglazed earthenware filled with dilute sulphuric acid, in which is placed a cylinder of amalgamated zinc

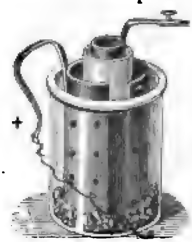

Fig. 370

When this battery is in action, water is decomposed; the oxygen goes to the zinc, forming oxide of zinc, which is dissolved by the sulphuric acid, giving sulphate of zinc. The hydrogen of the water goes to the sulphate of copper, and decomposes it into metallic copper and sulphuric acid; the former is deposited on the copper plate, while the latter goes to the zinc to replace that already used in forming sulphate of zinc. The result of these decompositions and recompositions is to keep up a current of electricity, which will continue as long as the outer vessel is kept full of the saturated solution of sulphate of copper.

546. Grove's Battery. — Fig. 371 represents one of the elements of this form of battery. The outer jar, which is made of glass, is partially filled with dilute sulphuric acid, and in this is placed a cylinder of zinc with a slit at the side for the passage of the liquid. The inner vessel is made of porous earthenware, and

contains ordinary nitric acid. A strip of platinum is suspended in this vessel, to which is attached a wire by means of a binding-screw; there is one also attached to the zinc in a similar manner.

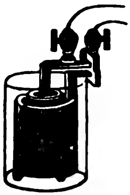
Fig. 371.

In this couple there is a double chemical action. Water is decomposed in the outer vessel, giving its oxygen to the zinc, forming oxide of zinc, which is taken up by the sulphuric acid, producing sulphate of zinc. This remains in solution. The hydrogen of the water passes through the porous cell, and uniting with a part of the oxygen of the nitric acid, decomposes it, reproducing water, and also forming nitrous acid, which escapes in fumes. This double action develops a large amount of electricity.

547. **Bunsen's Battery.** — In Bunsen's battery (Fig. 372) the platinum strip of the Grove is replaced by a cylinder of carbon. The couples are, however, larger than those of Grove's battery. The chemical action is the same.

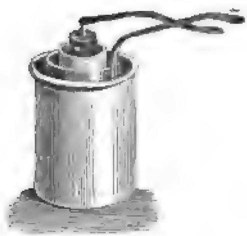
Fig. 372.

Both these batteries are very powerful. Grove's battery possesses some advantages over Bunsen's, but its first cost is much greater. Grove's battery is largely used in telegraphing, it being a battery of great intensity. The last three batteries are called "two-fluid" batteries.

The fumes arising from the Grove and Bunsen batteries render their employment impossible in cases where a large number of cells are necessary. To avoid these dangerous fumes bi-chromate of potash is sometimes substituted for nitric acid, and strong brine for sulphuric acid, but the power of the battery is then lessened. In central telegraph offices, where several thousand cells are likely to be used, Daniell's battery is found the most advantageous If properly cared for, it will keep for months in action.

548. **Ohm's Law.** — In a galvanic battery there are three objects of consideration: the *electromotive force*, or the force by which the electricity is set in motion in the voltaic circuit, the *resistance*, or the opposition to the passage of the

current; and the *intensity* of the electricity, or its power of traversing a conductor with marked effect. Intensity may be more accurately defined as the quantity of electricity which passes through a conductor in a unit of time.

The law established by OHM is expressed as follows: *The intensity of the current equals the electromotive force divided by the resistance.*

The resistance of a conductor depends upon three things: its conductivity, its cross-section, and length. The less the conducting power, the greater the resistance, the greater the cross-section, the less the resistance; and the greater the length, the greater the resistance. The larger the wire, the less obstruction to the passage of the current, and the longer the wire, the greater obstruction.

In an ordinary cell there are two resistances: that offered by the liquid conductor between the two plates, called the *internal* resistance, and that by the conductors outside, called the *external* resistance. The resistance of the liquid conductor is vastly greater than that of any metal. The distance between the plates is the length of the liquid conductor, and the size of the plates the area of its cross-section. When the internal and external resistances are equal, we get the most satisfactory results.

The unit of resistance is called an *ohm.* The resistance of an ordinary Daniell's cell is about half an ohm; of a mile of submarine telegraph cable, from four to twelve ohms. Copper wire $\frac{1}{16}$ of an inch in diameter has a resistance of about one ohm for sixty feet.

549. Quantity and Intensity.—A battery may develop a large amount of electricity with little intensity, or a small amount with great intensity. The intensity depends upon the *number* of cells, the quantity upon the *extent of surface.* If the external resistance is great compared with the internal, increasing the number of cells adds to the intensity; as in the case of the electric light, since the current must pass between the charcoal points through the air-space, the resistance must be great and the number of cells should be large.

To secure great intensity we can form a battery of couples, Bunsen's for example, by connecting the zinc cylinder of one couple with

the carbon cylinder of the next, as shown in Fig. 373. This is called a battery of ***high resistance***, or intensity battery.

If the external resistance is small, not much is gained by increasing the number of cells, as the internal resistance increases in the same proportion; but the best effects are secured by increasing the size of the plates, or, as in the Bunsen battery, by connecting all the zinc cylinders together so as to form one great zinc cylinder, and all the carbon cylinders to form one great carbon cylinder.

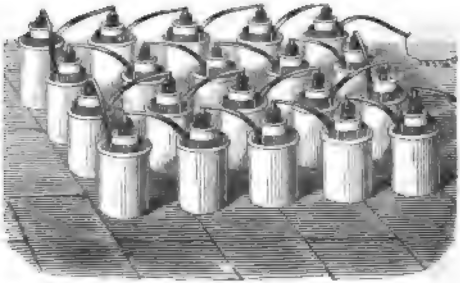

Fig. 373.

A battery so arranged yields large quantities of electricity, and is called a battery of *low resistance*, or *quantity* battery. Such a battery is desirable when a great amount of heat is wanted in melting an iron wire, for instance. A few cells of large size, connected as stated above, are better for this purpose than many small ones.

For general use batteries of some intensity and considerable quantity are best. Very good results are obtained by making several groups of cells for quantity, and connecting these groups so as to have an arrangement for intensity.

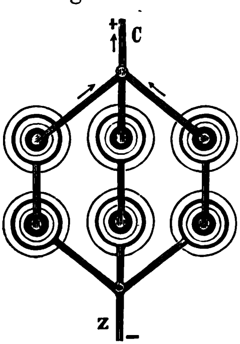

Fig. 374.

An excellent arrangement for a battery of six elements is represented in Fig. 374.

550. Frictional compared with Galvanic Electricity. — There are several peculiarities which distinguish galvanic from frictional electricity. It will not pass through non-conductors,

like frictional electricity; the current begins and continues steadily with the chemical action in the cells, whereas frictional electricity accumulates and is discharged with instantaneous explosive power; voltaic electricity also clings to conductors with more pertinacity than frictional, which makes it available for telegraphing.

The electricity of the machine is small in quantity, but of enormous intensity; that of the battery, of enormous quantity but slight intensity. It is the intense energy of the former that enables it to pass through poor conductors, as the lightning through the intervening air, while the feeble energy of the latter allows it to pass through only the smallest interval of air, but makes it follow the conducting wire with faithful accuracy from continent to continent.

TYNDALL compares frictional electricity to a cubic inch of air, which, if compressed with sufficient power, may be able to rupture a very rigid envelope; and voltaic electricity to a cubic yard of air, which, if not so compressed, may exert but a feeble pressure upon the surfaces which bound it.

The positive conductor of an electrical machine corresponds to the positive pole of a galvanic battery, and the negative conductor to the negative pole, and the friction on the plates to the chemical action in the couples.

Summary. —

Voltaic Batteries.
- Definition.
- Voltaic Pile.
- Pile illustrated by Figure.

Constant Batteries.
- Disuse of Voltaic Pile.
- Action of Constant Battery.
- Smee's Battery.
- Potassium Bi-chromate Battery.
- Mercury-Sulphate Battery.
- Daniell's Battery.
- Grove's Battery.
- Bunsen's Battery.
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Ohm's Law.
Definition of Terms.
Statement of the Law.
External and Internal Resistances.
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Quantity and Intensity of Electricity.
Illustrated by Figure.
Batteries of High and Low Resistances.
Arrangement of Six Elements illustrated by Figure.
Frictional compared with Galvanic Electricity.
Illustrations of their Differences.
Tyndall's Comparison of the Two.

SECTION II. — APPLICATIONS OF GALVANIC ELECTRICITY.

551. **Effects of the Galvanic Battery.** — The EFFECTS OF THE GALVANIC BATTERY may, for convenience of study, be divided into *physiological*, *heating*, *illuminating*, *chemical*, and *magnetic*. They are all due to the recombination of the two electricities, as in machine electricity, but they are more remarkable and more energetic, because of their continuous action.

552. **Physiological Effects.** — The PHYSIOLOGICAL EFFECTS of galvanic electricity are a succession of shocks producing violent muscular contractions, not only in living, but in dead animals, as shown in the case of GALVANI'S frog

If we touch but one of the poles of a galvanic battery, no shock is felt, but if we take both electrodes in our hands, which have been moistened with acidulated water to increase the conductivity, we feel a sensation similar to a shock from a Leyden jar, with this difference, that the latter is instantaneous, while that from the galvanic battery is continuous. The battery must be very powerful, otherwise the sensation will hardly be perceptible. The action of the battery keeps up a continuous supply of the two electricities, which supplies the place of that lost by recombination in passing through the body of the experimenter.

The effect of galvanic electricity upon the bodies of dead animals is peculiarly striking. It produces violent contractions of the muscles, causing motions similar to those of the living being.

553. **Heating Effects.** — When a current of galvanic electricity is passed through a conductor, it becomes heated, and often to such a degree as to produce fusion or even vaporization. When a powerful current is passed through a wire of very small diameter, it soon becomes incandescent, and then melts or is dispersed in vapor, and burns with splendid brilliancy.

The smaller the wire and the less the conducting power, the greater the resistance to the current, and the more intense the heat. Silver burns with a greenish light, much smoke arising from the vaporization of the metal. Gold burns with a bluish white light. Platinum, which is infusible in the most intense heat of our furnaces, melts into spherical globules with a dazzling light. Carbon is the only body which has not been fused by galvanic electricity. DESPRETZ, however, by passing a current through small rods of pure carbon, succeeded in softening them so much that they could be bent and made to adhere, which indicates an approach to fusion.

The heat thus developed is used in firing nitro-glycerine and gunpowder blasts even under water. The explosive substance is placed in a tightly closed vessel, and through it a fine platinum wire is connected at either end with the wires from a battery. On account of the fineness and poor conductivity of the platinum it offers great resistance to the passage of the current, and, becoming red-hot, ignites the charge. We can show that the heat produced is proportioned to the resistance it encounters in the conductor by passing a strong current of electricity through a chain composed of alternate links of silver and platinum; the platinum becomes red-hot, while the silver remains dark.

554. **Illuminating Effects.** — The heating effects just described are accompanied with a disengagement of more or less light; but to obtain the most brilliant electrical light possible, dense carbon points are employed. They are at first placed in contact, one being connected with the positive, and the other with the negative pole of a powerful galvanic bat-

tery. The points immediately become incandescent, emitting a light of dazzling brightness.

If the points are slightly separated (Fig. 375), the current still continues to pass between them, and the light takes the form of a luminous arc, called the *voltaic arc*. The point connected with the positive pole wastes away, while the other increases in size; hence we conclude that particles of carbon are for the most part transported from the former to the latter: this explains how the current continues to pass in spite of the interval which separates them. The incandescent particles are seen traversing the arc, sometimes in one direction and sometimes in the other, the prevailing direction, however, being that of the positive current.

Fig. 375.

This action is more manifest in a vacuum where a sort of cone grows upon the negative carbon, while a conical cavity is found in the positive; there is no combustion in the vacuum, but only a transferrence of particles as mentioned.

In the figure, which represents the arc in its simplest form, the distance between the points is regulated by hand, but in practice this is more effectually accomplished by automatic regulators.

The subject of the electric light will be further considered under the head of Magneto-electricity.

555. Chemical Effects. — The most important chemical effects produced by galvanic electricity are the decomposition of chemical compounds in solution, and the transportation of their elements.

Substances thus decomposed are called *electrolytes*; the process is called *electrolysis*.

To analyze water we may employ the apparatus shown in Fig. 376. It consists of a glass dish with a wooden bottom. Rising from the bottom are two platinum wires, which pass through the wooden stand and terminate in the tubes, *a* and *b*. These wires serve as electrodes.

The glass vessel is partially filled with water, to which a small

quantity of sulphuric acid is added to improve its conducting power, for pure water is a very imperfect conductor. Two narrow bell-glasses, *H* and *O*, are filled with water and inverted over the two platinum wires. The tube, *a*, is then connected with the positive pole of the battery, and the tube, *b*, with the negative pole. A current is set up from one wire to the other through the water, and decomposition begins, as is shown by bubbles of gas rising in the two bell-glasses.

By testing the gases thus obtained, we find that in the glass, *O*, corresponding to the positive pole of the battery, is pure oxygen, while that in the glass, *H*, corresponding to the negative pole, is pure hydrogen. We see also that the volume of hydrogen is twice

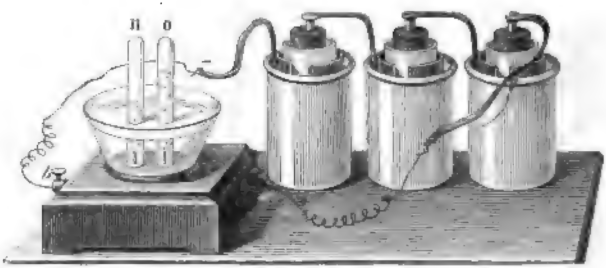

Fig. 376.

that of the oxygen. This experiment shows that water is composed of oxygen and hydrogen, mixed in the proportion of one volume of the former to two of the latter.

The bodies separated at the positive pole are *electro-negative*, as they are supposed to be charged with negative electricity, and those separated at the negative are *electro-positive*. Most of the metals go to the negative pole, and the non-metallic substances to the positive, when the electrodes are plunged into solutions of compounds like chloride of copper, iodide of potassium, sulphide of iron, etc.

556. Application of Electricity to Electrotyping. — Electrotyping is the operation of copying metals, wood-cuts, types, and the like, in metal, by the aid of galvanic electricity.

The first step is the preparation of a mould of the object

upon the accuracy of which depends the success of the entire operation. An impression of the object is taken in wax. The surface of the mould to be copied is brushed with powdered graphite, to increase its conducting power.

Fig. 377 shows the method of depositing the metal upon the mould. *M* is a vessel filled with a solution of sulphate of copper; *A* and *B* are metallic rods communicating with the two poles of the battery; the mould is suspended from the rod, *B*, and facing it is a plate of pure copper suspended from the rod, *A*; these constitute the electrodes, the mould being the negative one.

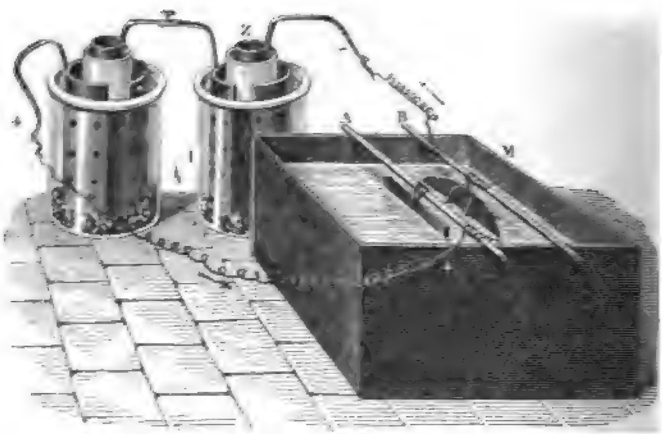

Fig. 377.

The current which is set up through the solution of copper between the electrodes decomposes the sulphate into sulphuric acid and pure copper. The sulphuric acid goes to the copper plate, and, uniting with it, produces sulphate of copper; the pure copper goes to the negative electrode, that is, to the mould, and is there deposited. After about twelve hours, or four hours with powerful batteries, the coating of copper becomes thick enough to be removed from the mould, and it then presents a fac-simile of the object to be copied. In copying medals, each face is copied separately, and the two are united by means of some fusible metal placed between them.

557. Electro-plating and Electro-gilding. — The process of covering bodies with thin coatings of gold or silver is analogous to that of electrotyping. The perfection of the process consists in making the coating of gold or silver not only of uniform thickness, but also closely adherent.

The method of silvering, or electro-plating, is shown in Fig. 378. The object to be silvered is suspended in a bath of a silver solution by a metallic rod which connects with the negative pole of a battery. Immediately below it is a plate of pure silver, which is connected with the positive pole of the battery. The object to be silvered and the

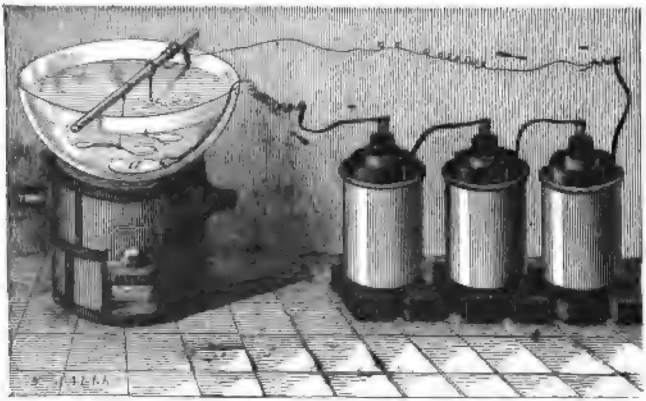

Fig. 378.

silver plate, *a*, constitute the electrodes, *a* being the positive one. The explanation of the process is analogous to that in the preceding article.

The salt of silver generally employed is a cyanide of silver, which is dissolved in cyanide of potassium. The thickness of the coating deposited will depend upon the power of the battery and upon the time of immersion.

The process of electro-gilding is the same as that of silvering, except that we use a cyanide of gold, dissolved in cyanide of potassium, and a plate of gold at *a*, instead of a silver one.

A vessel may be "gold-lined" by filling it with a solution of gold, suspending in it a slip of gold from the positive pole of the battery,

and then attaching the negative pole to the vessel. In a short time a thin layer of gold will cover the surface.

Summary. —

Effects of the Galvanic Battery.

Physiological. — Experiments.

Heating (with metals and carbon).

Method of exploding Nitro-glycerine and Gunpowder by Battery.

Illuminating.

The Voltaic Arc. — How formed. — Illustrated by Figure.

Chemical.

The Analysis of Water, explained by Figure.

Application of Electricity to Electrotyping.

Definition of the Term.

Preparation of the Mould.

Deposition of the Metal illustrated by Figure.

Application of Electricity to Electro-plating and Electro-gilding.

Process illustrated by Figure.

SECTION III. — FUNDAMENTAL PRINCIPLES OF ELECTRO-MAGNETISM.

558. Relation between Magnetism and Electricity. — It was observed at an early period that the magnetic and electrical forces had many analogous properties. In each case like poles repel, while unlike attract. It was also observed that a stroke of lightning often reversed the poles of a magnetic needle, and sometimes completely destroyed its magnetism. The two have also points of dissimilarity. Magnetism is not transmitted, like electricity, through conductors. A magnet does not, like an electrified body, return to a neutral state when brought into communication with the earth. Magnetism can only be developed in a few, whereas electricity may be developed in all bodies.

Between these analogies and dissimilarities nothing positive could be affirmed with respect to the identity of magnetism and electricity, until, in 1819, OERSTED made a discovery which showed that these physical agents are most intimately allied, if not identical. They are now regarded, as previously stated, by physicists generally, to be identical.

559. Action of an Electrical Current upon a Magnet. — OERSTED discovered the fact that an electrical current has a directive power over the magnetic needle, tending always to direct it at right angles to its own direction.

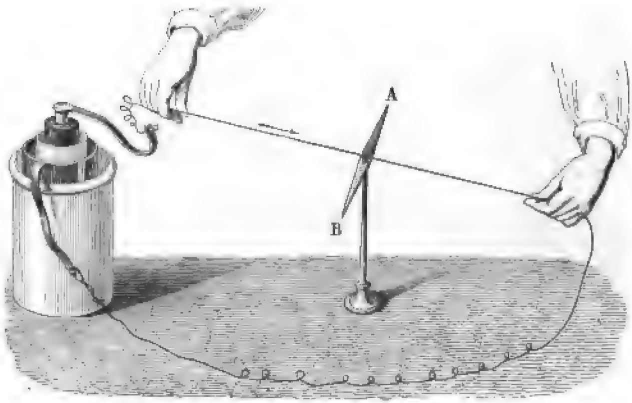

Fig. 379.

This action may be shown by the apparatus represented in Fig. 379. If a wire be placed parallel to and pretty near a magnetic needle, and then a current of electricity be passed through it, the needle will turn around, and after a few oscillations will come to rest in a position sensibly at right angles to the current. That it does not take a position absolutely perpendicular to that of the current is because of the directive force of the earth, which partially counteracts that of the current.

The direction towards which the north end of the needle will turn depends upon the direction of the current. If that flows from south to north, and above the needle, the north pole of the needle deviates towards the west; if it flows towards the south, and above

the needle, the north pole of the needle deviates towards the east. When the current flows below the needle, the phenomena are reversed.

560. Ampère's Law. — AMPÈRE, to whom the discovery of the greater portion of electro-magnetic phenomena is due, gave a simple expression to the law which governs the action of a current upon a magnet. He supposes an observer lying down upon the wire along which the current flows, the current entering at the feet and going out at the head. Then, if he turn his face always towards the needle, the north pole will in all cases be deviated towards his left hand.

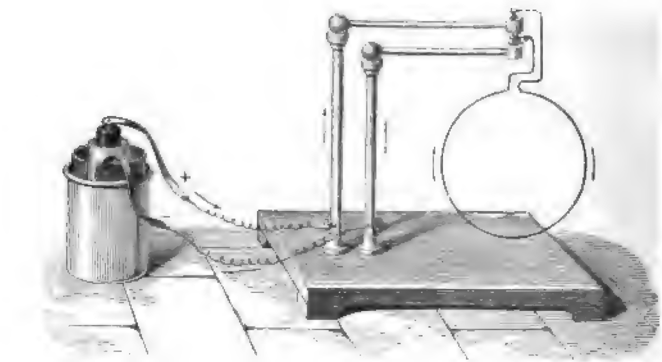

Fig. 380.

561. Action of Magnets upon Currents, and of Currents upon Currents. — AMPÈRE established the following principles : —

1. Magnets exercise a directive force upon currents.

To illustrate this, we bend a copper wire into a circular form, and then dip its extremities, which should be pointed with steel, into cups of mercury, one above the other, as shown in Fig. 380. These cups communicate with the two poles of a battery, by means of which a current may be generated, flowing as indicated by the arrows. Now, if a bar magnet be brought near this current, the axis being in the plane of the current, we shall see the hoop turn about the steel points in the cups, and come to rest, [illegible] its plane perpendicular to the axis of the magnet.

2. The earth, which acts like a huge magnet upon a magnetic needle, acts in the same manner upon movable currents; that is, it directs them so that they are perpendicular to the magnetic meridian.

This may be shown by the apparatus of Fig. 380. If the communication with the battery be cut off, and the hoop be turned till its plane coincides with the magnetic meridian, it will remain in that position. If now a current be passed through it, we see it turn slowly around the pivots, so as to take a position at right angles to the meridian. It will turn in such a direction that the current in the lower part of the hoop will flow from east to west.

3. The wires of two parallel currents attract each other when the currents flow in the same direction, if there is freedom of motion for the wires, and repel each other when they flow in opposite directions.

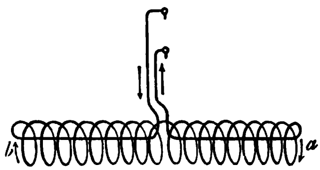

Fig. 381.

4. If a wire be coiled as represented in Fig. 381, and then be suspended by its steel points in the cups of mercury (Fig.

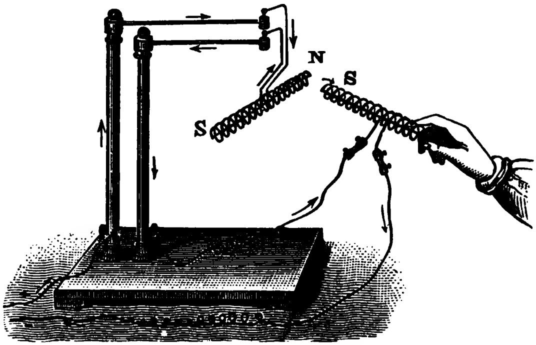

Fig. 382.

380), it will, when a current is passed through it, arrange itself in the meridian like a magnetic needle.

When the current takes the direction of the arrows, the end, *a*.

is directed towards the north. The spiral in Fig. 381 is technically called a *helix*. When thus suspended, the helix has all the properties of a magnet, and is subject to the same laws of attraction and repulsion. A helix of the kind described is called a *solenoid*. A solenoid is only complete when its wire passes in the direction of the axis in the interior of the helix. If two solenoids are brought near each other, as represented in Fig. 382, like poles will repel and unlike attract, as in the case of a magnet.

562. Ampère's Theory of Magnetism. — From the facts explained in the last article, AMPÈRE deduced a theory of magnetism. He supposes magnetism to be due to currents of electricity flowing around the ultimate molecules of a magnet, always in the same direction. In a body not magnetized these currents are supposed to have directions not parallel. The currents in the interior of the magnet neutralize each other, as their adjacent parts oppose one another, and consequently the total effect of all the currents in a magnet is the same as that of a set of surface currents flowing around the magnet in such a direction that if we place the eye at the south end of a magnet, and look in the direction of the axis, the current will flow around in the same direction as the hands of a watch.

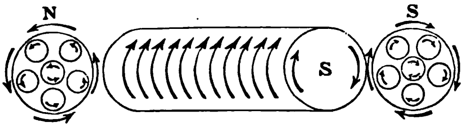

Fig. 383.

In Fig. 383 we have the large circles, *N* and *S*, with the surface and molecular currents represented. *N* and *S* are the north and south ends of a magnet. Between these two ends is a magnet with its parallel surface currents.

This theory explains why like poles repel and unlike attract. If unlike poles are brought near each other, the electric currents on their adjoining sides will have the same direction; and since two currents having the same direction attract each other, the two poles will also attract each other. If like poles are brought together, the current of the adjacent sides will have opposite directions, and the poles will repel each other.

563. The Galvanometer. — Galvanic Multiplier.— A GALVANOMETER is an instrument for measuring the force of an electrical current. In its simplest form it consists of a magnetic needle (*a b*, Fig. 384) with a conducting wire passed around it in the direction of its length.

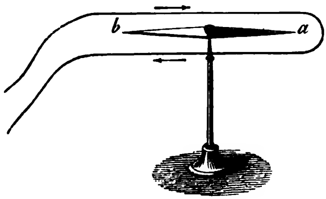

Fig. 384.

When a current of electricity is passed through the wire, its presence will be indicated by a motion of the needle, its force by the amount of deviation of the needle, and the direction of the current will be indicated by the direction towards which the north end of the needle deviates.

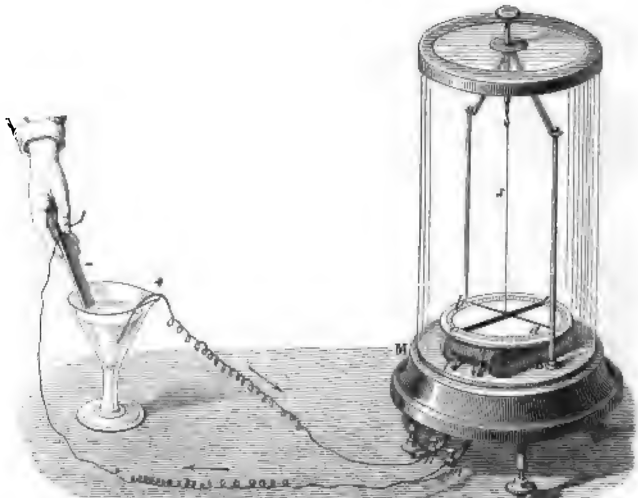

Fig. 385.

The GALVANIC MULTIPLIER is a *galvanometer* of great sensitiveness, but constructed on the same principles as the one already described.

It is represented in Fig. 385. It consists of a copper stand, *M*,

supporting a glass cylinder, as shown in the figure. Under the cylinder is a graduated circle, beneath which is a wooden frame wound with a great number of coils of copper wire. The wire is insulated by being covered with silk. The two ends of the coil communicate with the binding-screws, *m* and *n*, by means of which they may be made to communicate with the poles of a voltaic couple. A metallic frame supports a hook, from which is suspended a delicate silken cord, *s*. This cord supports two fine magnetic needles, the one, *a b*, above the graduated circle, and the other, *B*, within the coil, only a part of which is visible in the figure. The two needles are so united that one cannot turn without the other, and their poles being placed in opposite directions, the action of the earth upon them is completely neutralized. Hence they are free to obey the least force.

This combination of needles is called an *astatic* needle, and the galvanometer in which it is used an *astatic galvanometer*.

564. Uses of the Galvanic Multiplier.—The multiplier is used to indicate the feeblest currents of electricity. By means of it BECQUEREL established the fact that a current is developed in every chemical action, in the imbibition of liquids, and in many other phenomena. By using a galvanometer with many thousands of turns of wire, the existence of electrical currents in animals and vegetables may be demonstrated.

To show the currents developed by chemical action, as, for example, the action of acids upon metals, two fine platinum wires are introduced into the binders, *m* and *n*. One end of one of the wires is then dipped into a glass of dilute sulphuric acid, and the other is held in contact with a plate of zinc, which is also dipped into the dilute acid. The two needles which were before parallel to *o i*, and which we suppose to have been placed in the magnetic meridian, immediately turn round and become perpendicular to the meridian, indicating the instantaneous production of a current.

565. Magnetizing by means of an Electrical Current.—If a wire be wound around a bar of iron, and a current of electricity be passed through the wire, it is at once converted into a magnet. The method of making the experiment is shown in Fig. 386.

If the current cease, the iron bar at once loses its magnetism. We may in like manner form a permanent magnet by using a bar of steel instead of a bar of iron.

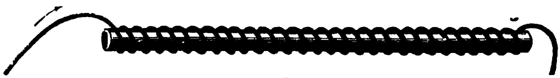

Fig. 386.

The bar of steel may also be magnetized by passing through the wire a spark from a Leyden jar. To do this, one end of the wire is made to touch the external covering of the jar, and the other end is brought into contact with the button of the jar. The steel bar is magnetized instantaneously, thus showing the identity between the electricity of the galvanic current and that of the Leyden jar.

Summary. —

Relation between Magnetism and Electricity.

Action of an Electrical Current upon a Magnet.

Illustrated by Figure.

Ampère's Law.

Action of Magnets upon Currents, and of Currents upon Currents.

1. Magnets exercise a Directive Force upon Currents.
2. The Earth acts like a huge Magnet upon Movable Currents.

   Illustrated by Figure.
3. Action of Parallel Currents upon each other.
4. Action of the Current upon a Helix suspended in Cups of Mercury.

   Illustrated by Figure.

Action of two Solenoids upon each other illustrated by Figure.

Ampère's Theory of Magnetism.

Illustrations.

Like Poles repel and Unlike attract, explained by Figure.

Galvanometer.

Action illustrated by Figure.

Galvanic Multiplier.

Description by Figure.

Use and Mode of Action.

Magnetizing by means of an Electrical Current.

Method illustrated by Figure.

SECTION IV. — ELECTRO-MAGNETIC TELEGRAPHS. — THE ELECTRO-MOTOR.

566. The Electro-magnet. — An ELECTRO-MAGNET is a magnet obtained by the use of electricity.

Electro-magnets are generally made of soft iron, bent in the form of a horse-shoe, as shown in Fig. 387. Upon each branch is wound a great number of coils of wire, insulated by being covered with silk. In order that the two ends of the horse-shoe may have opposite polarities, the wire must be coiled on the two limbs, *A* and *B*, in such a way that if the magnet were straightened out it would run in the same direction; its extremities are then connected with the poles of a battery.

Fig. 387.

In this way magnets may be constructed of immense power, so powerful, in fact, as to support the weight or ten of twelve persons. Fig. 367 represents the method of arranging the details of a magnet which is intended to exhibit a great *sustaining power.*

The plate in contact with the two poles is called an *armature.*

When the instrument is of soft iron it is magnetized instantaneously by the passage of a current of electricity through the wire, and as instantaneously loses its magnetism when the current is stopped, or *broken.* This property has been utilized in the electro-magnetic telegraph.

The helix itself becomes magnetized as well as the soft iron. Let a current pass through a helix, as shown in Fig. 388; a rod of iron placed below it will be drawn up by the action of the magnetized coil.

Fig. 388.

567. The Electrical Telegraph. — AN ELECTRICAL TELEGRAPH is an apparatus for transmitting intelligence to a distance by means of electrical currents. MORSE'S telegraph is more extensively used than any other, and the principle on which it is operated is very simple.

At the station from which a telegram is despatched is an electrical battery, and at the one where it is to be received is an electro-magnet. The two are connected by a wire running between the stations. When the current is transmitted through the wire, the iron becomes magnetized and attracts an armature of soft iron, which in turn imparts motion to other pieces, by means of which the signals are imparted. When the current ceases, the iron loses its magnetism, and a spring forces the armature back to its primitive position. By successively breaking and restoring the current, the telegram is transmitted. As a matter of fact, however, each station has the ***transmitting*** and ***receiving*** apparatus.

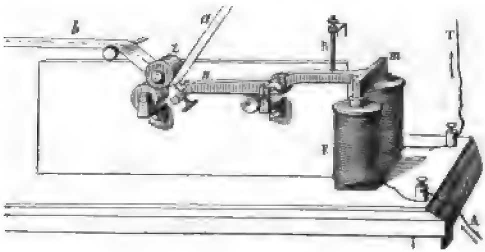

Fig. 389.

568. The Register. — One form of the receiving apparatus is the register represented in Fig. 389, which is composed of an electro-magnet, E, which, whenever a current is transmitted, as at A, acts by attraction upon an armature of soft iron, m, fixed at the extremity of a lever, mn, and movable about an axis. At its extremity, n, the lever carries a point, x, which may be made to press against a movable slip of paper, ab. When the current does not pass through the electro-magnet, the point, x, does not press against the paper; but as soon as the current passes, the point is pressed against the paper, and traces upon it either a point or a line more or less elongated, according to the length of time during which the current is uninterrupted.

The slip of paper is kept in motion uniformly by means of a train of clock-work, which turns the cylinder, *Z*. The slip of paper moving uniformly in the direction from *a* to *b*, the operator at the other station, by pressing the button of the key, and maintaining the pressure for greater or lesser periods of time, causes a succession of points and marks to be made upon the paper at pleasure. The current, after making the circuit of the helix, passes out at *T*.

The register just described is now going out of use, and an instrument called the "sounder" is employed. It is simply a register without the slip of paper and clock-work attachment. The message is read by the operator from the clicking of the armature, and copied by himself, whereas in large offices, when the recording apparatus was used, an operator was employed to read the despatch from the slip of paper as it came from the instrument, and a copyist stood ready to write it down. By means of sound-reading the expense thereby is much lessened.

The following table contains the characters of Morse's alphabet, now in general use throughout the world: —

-—	—---	-- -	—--	-	-—-	——-	----	--	—-—-
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*
—-—	——	— —	—-	- -	-----	--—-	- --	---	—
k	*l*	*m*	*n*	*o*	*p*	*q*	*r*	*s*	*t*
--—	---—	-——	-—--	-- --	--- -	- ---	——-	--—--	
u	*v*	*w*	*x*	*y*	*z*	*&*	1	2	
---—-	----—	———	------	——--	—----	—--—	——		
3	4	5	6	7	8	9	0		
-—-—	-—-—-	--——--	—--—-	———-					
,	;	.	?	!					

A space about equal to the length of a dash is left between two letters, and a space about twice this length between two words.

569. Key for Transmitting. — For opening and closing the circuit in the transmission of messages, an apparatus called the *key* is used. It consists (Fig. 390) of a metallic lever, on one end of which is a knob, *X*. At *T* are two platinum points, one on the lever and the other on the metal-

lic plate below. *C* and *D* are the wires through which the current passes.

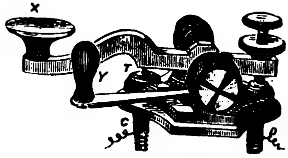

Fig. 390.

The operator, to close the circuit and send the message, presses the knob down and brings in contact the two platinum points at *T*. The current will then pass through the metallic connections out at the wire, *D*, to the next station. *Y* is a movable brass arm that slides under a lip for the purpose of closing the circuit when the key is not in use. A spring under the lever keeps the platinum points separated when the pressure is removed from the knob. The knobs, *Y* and *X*, are both non-conductors to protect the operator from electric shocks.

570. The Relay. — It is only when the stations are a short distance apart, generally less than fifty miles, that the receiving instrument is operated directly by the line current. In long distances this becomes too feeble to do this effectively, but by allowing the main current to enter an instrument called the *relay*, a local current is generated to work the register or sounder.

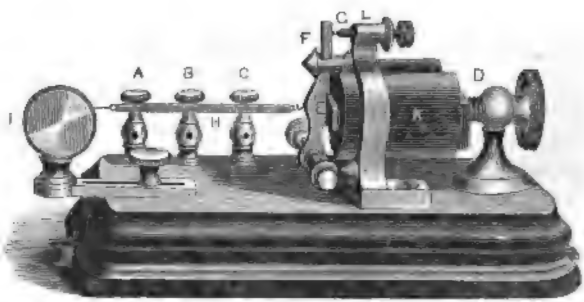

Fig. 391.

The line wire enters at *D* (Fig. 391), traverses the helix and passes out at *C* to the ground, or if it be a way-station to the main line. A wire from *A* connects with the positive pole of a local battery of two or three cells. A wire from *B* goes to the register or sounder, and

thence to the negative pole of the battery, forming the complete local circuit.

When the distant operator transmits a message by means of the key along the main line, it passes at D through the magnet, K, and causes the armature, E, to move back and forth in front of the magnet, and to exactly reproduce in its movements the interruptions of the current made by the key of the operator.

The backward motion of E is produced by a spring which is regulated at H; the forward motion, of course, by the attraction of the magnet. When E moves forward it brings the lever, F, in contact with G, and thus operates the local circuit.

The register or sounder, which is included within this circuit, is worked in precisely the same way that the key affects the relay, only with far greater force.

571. **Lightning Arresters.** — Experience has shown that the wires may, from atmospheric influences, accumulate upon themselves sufficient quantities of electricity to prove troublesome to the operators of the telegraph. To prevent any injurious action of this kind, an arrangement is sometimes used composed of two toothed pieces of metal, disposed so that the teeth are nearly in contact. The current passes into one of these pieces, while the other is in communication with the earth. If, from any atmospheric change, electricity accumulates upon the wires or apparatus, it is given off by the points to the piece which is in communication with the earth, and shocks are thus avoided.

Other forms of lightning protectors have been devised that are simple and effective. It is not necessary that the lightning should be carried to the earth, but only diverted from the relay magnet. An inexpensive way of turning aside the lightning, and one of which every operator can avail himself, has been suggested. Let a wire, larger than that of the relay magnet, and a few inches in length, run from each main circuit binding-screw of the relay, and end in a small bottle of water. The wires must not come together, but their distance from each other can be varied according to circumstances.

Water being a poor conductor of voltaic electricity, little is lost, most of it preferring the magnetic wire; but atmospheric electricity, by its great intensity, takes the short water-route. These devices are not an absolute protection; but during a severe thunder-storm

relays should be cut off from the main line, but in such a manner as not to break it.

572. **The Circuit.** — In what has been said, only a single wire has been spoken of as running from station to station. This is generally an iron wire which passes over glass insulators attached to tall wooden posts. When the wires are laid under ground or in water, they are insulated by a coating of gutta-percha. Copper wires are commonly used in offices.

It would seem necessary, in order to complete the circuit, that a second wire should be employed. Such, however, is not the case. The employment of a second wire is avoided by connecting the two ends of the single wire with the earth. When gas or water pipes enter an office the ground wire is attached to them.

If there are no such conveniences, copper plates several feet square at each station are buried in a perpendicular position, at sufficient depth so as to be always in contact with moist earth. The circuit is thus completed. At the station where the message is sent the line is connected with the positive pole of the battery, and the current passes over the wire down through the earth back to the negative pole. This simple device saves not only half the expense in constructing wires, but greatly increases the power of electrical transmission, the resistance it offers compared with the wire being practically nothing.

Since the earth is the common reservoir of neutral electricity the electric current from the wire is really dissipated when it communicates with it. There is not supposed to be any real passage of the electricity back to the battery from which it started. The intermediate offices are supplied with ground wires, to be used only in case of trouble on the line.

573. **Plan of a Way-Station.** — In Fig. 392 we have represented a plan of the instruments and connections of a way-station. The line enters at L, passes through the lightning arrester, X, traverses the coil of the relay, M, and then passes through the key, K, back to the lightning arrester, and then to the next station by the line, L'. The dotted lines

represent the local circuit, and E' the local battery that is operated by the relay, M. The sounder, S, which is included in the circuit, is also operated. Instead of the sounder a register might be substituted.

By turning the button, C, the current passes along the main line without going through the instrument. The switch, Q, can be used

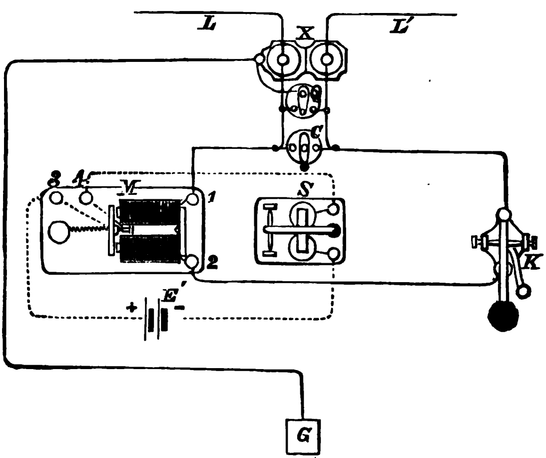

Fig. 392.

to connect the line on either side of the instruments with the earth at G. The line connected with the ground at G can then be worked independently of the other.

A plan of a terminal station would have a large main battery, and would dispense with the "cut-out," C, and the line, L'; in other respects it would agree with the plan of a way-station.

574. Other Forms of Telegraphs. — Other systems of telegraphy besides MORSE'S are used to a greater or less extent. The most ingenious of these are BAIN'S electro-chemical telegraph, and the printing telegraphs of HOUSE, HUGHES, and PHELPS.

In BAIN'S telegraph there is no magnet used, but a small steel point connecting with the line wire, when the current passes, presses upon the roll of paper that has been previously soaked in ferrocya-

nide of potassium, and which rests upon a metallic plate. When the point touches the paper the chemical preparation is decomposed, and blue marks are left on the paper, due to the formation of Prussian blue.

Of the three printing telegraphs, that of PHELPS is the most serviceable, and is a combination of HOUSE'S and HUGHES'S with the improvements of PHELPS.

The sending instrument has twenty-eight keys arranged like those of a piano; upon these are printed the twenty-six letters of the alphabet, and two punctuation points. When the operator depresses the keys, the circuit is closed, and the message is *printed* at the other end of the line in ordinary letters. This system works faster than MORSE'S, and the message does not have to be transcribed.

575. Duplex and Quadruplex Telegraphy. — Duplex telegraphy refers to that system of telegraphing by which messages are simultaneously sent in opposite directions on one and the same wire, thereby doubling the working capacity of the line. Quadruplex telegraphy refers to the system of telegraphing whereby *four* messages, two in each direction, may be simultaneously transmitted over one and the same wire. The quadruplex system has been extensively employed within a few years by the Western Union Telegraph Company, and is at present in use between almost all the principal cities in the country.

A detailed description of these systems, however, would be beyond the scope of the present work.

576. Submarine Cables. — Since the invention of the telegraph, a complete network of lines has been established over both continents. Not only have thousands of miles of wires been stretched on land, but submarine wires have been laid, connecting places separated by thousands of miles of water. Telegraphic wires connect England and Ireland, England and France, France and Algiers, Europe and America.

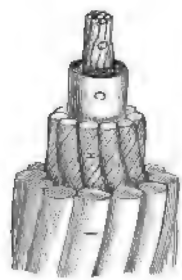

Fig. 393.

The Atlantic cables (Fig. 393) consist of (1) a central conducting strand, *O*, of seven copper wires ; (2)

surrounding this an insulating coat, *C*, of gutta-percha; (3) a layer of several strands of tarred hemp, *H*, to protect the gutta-percha; and (4) outside of all, eighteen iron wires, *I*, as a protecting sheath.

The signals are indicated by means of Sir Wm. Thomson's reflecting galvanometer, an instrument of extreme delicacy, without which the practical success of the Atlantic cable would have been a matter of great doubt.

A needle with a very light mirror attached is suspended by a silk thread within a coil of insulated copper wire; at a distance of a yard is a scale with zero in the centre and the graduation extending on each side. Under the zero point is an aperture through which the light comes from a gas or lamp flame, and strikes on the mirror and is then reflected upon the scale. The spot of light is deflected to the right or left according to the current, and these deflections correspond to the dots and dashes of Morse's alphabet.

577. **The Fire-Alarm Telegraph.**—Electricity is now widely used in many places to indicate the locality of fires. The apparatus employed is really a modification of Morse's telegraph. In various parts of the city or town are small boxes, called *signal-boxes*, which are connected with a central station by means of wires.

When a fire occurs in the vicinity of any box, by turning a crank within the box the circuit is opened and closed, and the number of the box thereby telegraphed to the central station. This station is also connected with bells by wires at different points, and when the watchman on duty here receives notice of a fire as stated above, he strikes, by means of the electric current, on the bells the number of the box in whose neighborhood the fire is, so that the firemen know almost the precise locality of the fire.

578. **Electro-magnetic Motor.**—Many attempts have been made, and with partial success, to employ electro-magnetism as a motor for the propulsion of machinery, but in all cases the expense has been so great as to preclude its economical use.

Fig. 394 represents an electro-magnetic machine. It is composed

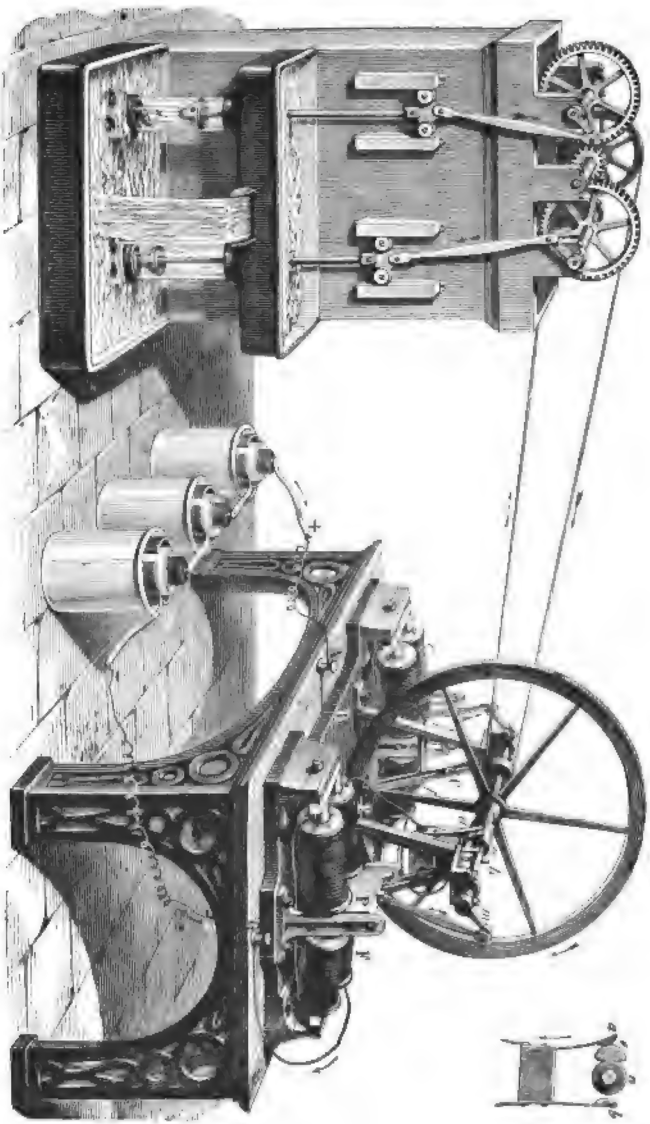

Fig. 394.

of four electro-magnets, acting in pairs upon two pieces of soft iron, *P*, only one of which is seen in the figure. These pieces, attracted by the electro-magnets, *E F*, transmit the motion by means of a working-beam, to a crank, *m*, fixed at the extremity of a horizontal arbor. The latter bears an iron fly-wheel, which regulates the motion. Finally, the same arbor supports a piece of metal, *n*, of a greater diameter, the use of which will be explained presently.

The current from the battery, *P*, entering *A*, passes into a platform of cast-iron, B, then, through different metallic pieces, it reaches the arbor and the piece, *n*. From thence the current flows alternately to the electro-magnets, *E F* and *e f*. The manner in which this alternate flow is effected is shown in Fig. 394, which represents a section of the piece, *n*, and its accessories. Upon the piece, *n*, is a projection, *e*, called a *cam*, which in the course of one revolution touches successively two pallets, *a* and *b*; these transmit to the electro-magnets the current, whose course is indicated by the unfeathered arrows. The feathered arrows in the figure show the direction in which the parts of the machine move.

The current passing alternately into the two pallets, *a* and *b*, and thence into the systems of electro-magnets, *E F* and *e f*, the piece, *P*, is first attracted, and then a similar piece at the other extremity of the arbor of the fly-wheel is attracted, and so on. The result is a continuous rotary motion, which is transmitted by a driving-band to a train of wheels, and so on to the pumps, which it is destined to work.

Summary. —

Electro-magnet.

Description by Figure.

Helix Magnetized. — Shown by Figure.

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Definition.

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The Register.

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The Relay.
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Lightning Arresters.
Atmospheric Electricity taken from the wires by means of Metallic Teeth.
Water as a Method of relieving the Wires.
The Circuit.
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Advantages.
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Illustrated by Figure.
Other Forms of Telegraphs.
Bain's, House's, Hughes's, and Phelps's.
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Explanation of Each.
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Explained by Figure.

SECTION V. — INDUCTION. — MAGNETO-ELECTRICITY. — THERMO-ELECTRICITY.

579. Induction by Currents. — We have seen that the electricity of the machine acts upon bodies by induction. The electricity of the battery acts in a similar manner, but only when the currents begin to flow and when they cease.

To show this, take two copper wires, covered with silk, and wind them side by side upon a bobbin. Then fasten the two ends of the first wire to the two binders, *m* and *n*, of the galvanometer (Fig. 385). Next connect one end of the second wire with one pole of a feeble galvanic battery. If the other end of the second wire be brought into contact with the second pole of the battery, at the instant of contact, the needle of the galvanometer will indicate the production

of a current in the first wire flowing in an opposite direction to that of the battery. If the contact is kept up, the flow of the induced current ceases, as is shown by the needle of the galvanometer returning to its position of rest. If the current of the battery is broken, the needle of the galvanometer is again deviated, but in a contrary direction, indicating an induced current flowing in the same direction as that of the battery.

The battery current is called the *primary*, or *inducing* current; the other current is called the *secondary*, or *induced* one.

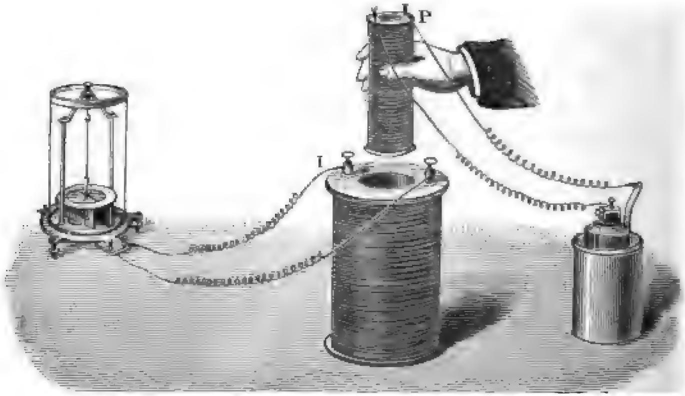

Fig. 395.

A current flowing in the same direction as the primary is called a *direct* current, but if flowing in the opposite direction, *inverse*.

Induced currents are also produced when a primary coil of wire, *P*, through which the current is passing (Fig. 395), is brought towards or removed from a secondary one, *I*. When brought towards it, the galvanometer indicates an *inverse* current in *I*, and also if placed *within* it, or if the intensity of the battery be increased.

If, however, the coil, *P*, be removed, or the primary current weakened, a *direct* current will be indicated in *I*.

580. Laws of Induced Currents. — These currents conform to the following laws: —

1. ***At the instant when the primary current begins to flow or to***

increase its intensity, an induced current, inverse and momentary, is developed in a neighboring circuit.

2. *A primary current approaching a conductor gives rise to an induced current, inverse and momentary.*

3. *At the moment the primary current ceases, or when its intensity diminishes, or when it is removed from an adjacent coil, an induced current begins, direct and momentary.*

581. Induction Coils. — An arrangement for producing an induced current in a secondary coil by breaking and closing, in rapid succession, the circuit of the primary, is called an *induction coil.*

Induced currents are the more powerful, the longer the wires employed. Hence in practice it is usual to wind the wires upon bobbins, as shown in Fig. 396.

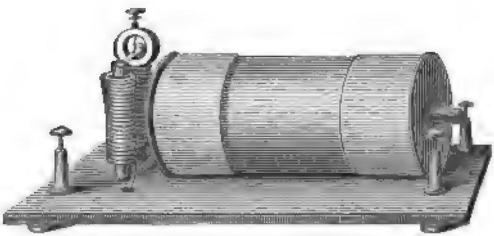

Fig. 396.

The coil shown in Fig. 396 consists first of a cylinder of several hundred coils of coarse copper wire. This is the inducing coil. Over it is a finer wire, making several thousand coils. These wires are not only covered with silk, but also with an insulating varnish of gumlac. At the extreme left of the stand on which the coil rests, are two binders in connection with the two poles of a battery.

A bunch of iron wires is inserted as a cone in the primary, or inner coil. The current-breaker consists of a small armature, at the left of the figure, attracted by an electro-magnet. When the primary current passes, the armature is attracted and immediately breaks the current. It then instantly flies back by means of a spring, and completes the circuit. By the passage of the current through the primary coil the bunch of iron wires is magnetized, and helps to strengthen

the induced current by induction. The intensity of the current is thus very much increased.

The primary coil is of coarse wire, so as to secure as strong a current as possible for magnetizing the bunch of wires; but in the secondary coil, as intensity is desired, fine wire enables us to bring more coils within range of the action of the primary coil and the bunch of wires. The two ends of the finer wire are also connected with binders, as seen at the right of the figure, and through them may be connected with any conductor whatever. For the purpose of administering a shock, the binders are provided with wires having metallic handles, which are to be grasped with the hands.

By the interruptions of the current the shocks produced are quite severe.

Electrical currents have been employed in the treatment of certain diseases, especially those connected with the nervous system. The induction coil and magneto-electric machine are used for this purpose. Electricity has a powerful action upon the animal economy, and when judiciously applied possesses considerable curative power.

582. Ruhmkorff's Coil. — The principle of induced currents has been applied in constructing instruments for generating large quantities of electricity. The induction coil, as improved by Ruhmkorff, is one of the most remarkable instruments of this class. In some of his larger instruments he uses more than sixty miles of wire in the secondary coil. In the largest size yet made the secondary wire is about 280 miles in length.

The dischargers are usually placed on a bar over the helices, and some of the most powerful instruments are capable of throwing sparks from twenty to forty inches long. The induction coil can be made to produce results similar to those of frictional electricity. It has the advantage which an electrical machine does not have, that it is not affected by the moisture in the atmosphere.

The coil can be used to charge and discharge Leyden jars. The sparks then resemble lightning flashes, and the sound produced is almost deafening.

The shocks from the larger coils are violent and even dangerous, and the heat is so intense as to melt and burn a fine iron wire with considerable brilliancy of light when placed between the ends of the secondary wire.

The brilliancy and beauty of the electric light from the coil is seen

when the current passes through Geissler's tubes. These are sealed glass tubes filled with rarefied vapors or gases; platinum wires are sealed into the ends of the tubes to conduct the current. Fig. 397 represents the current passing through a tube of hydrogen; in the bulbs the light is white, but in the connecting links it is red.

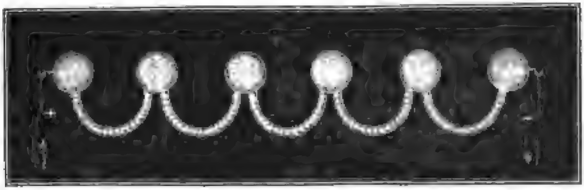

Fig. 397.

583. Magneto-electricity. — We have seen that a current of electricity passing through wires which surround a piece of soft iron magnetize it, and, conversely, a magnetized bar introduced into a coil of wire develops a current of electricity in the wire. Electricity produced by a magnet is called *magneto-electricity.*

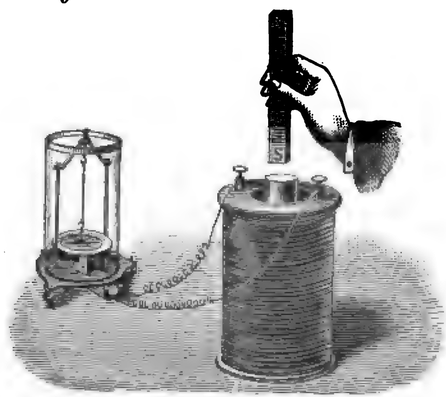

Fig. 398.

If we substitute for the primary coil represented in Fig. 395 a permanent magnet, we shall obtain results like those given in Art. 579.

We can produce the same effect if a bar of soft iron be inserted in the helix, and one end of a powerful permanent magnet brought near it, as shown in Fig. 398. The soft iron becomes magnetized by induction from the permanent magnet, and generates an electric current in the helix, causing the needle of the galvanometer to be deflected for an instant. If the magnet is kept stationary, it returns to its former position, but is deflected in the opposite direction when it is removed. The direction of the current changes with the poles of the magnet that are presented to the bar of soft iron, according to Ampère's law.

584. The Magneto-electric Machine. — Fig. 399 represents one form of the *magneto-electric machine.*

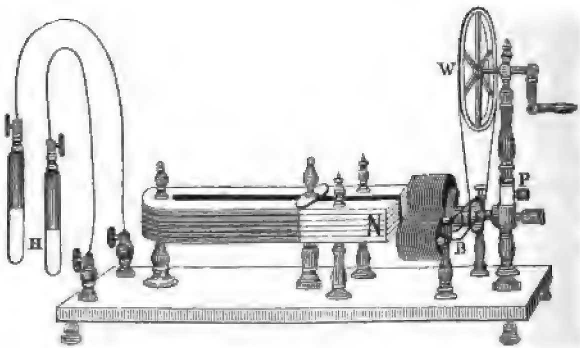

Fig. 399.

In front of the helix of a powerful horse-shoe magnet there is placed, as near as possible without touching, a bar of soft iron, *B*, rent at right angles, and surrounded with coils of insulated copper wires. The end of the wires connect underneath the stand with the screw-cup at the left hand. When this armature is made to revolve, the soft iron becomes magnetic by induction, and generates electrical currents in the coils of insulated wire. The poles are changed twice in every revolution, and thus the direction of the current changes twice in every revolution.

Sparks can be produced by this machine, water decomposed, and

wires made incandescent. If a break-piece be added, the circuit will be rapidly broken and closed, and a series of shocks will be felt by a person grasping the handles at *H*. The shocks will be more marked if the hands are first moistened with acidulated water.

Within the last few years magneto-electrical machines have largely increased in number and power. By means of these contrivances mechanical work is transformed into powerful electrical currents, which have been utilized in electro-plating and telegraphing, but especially are they successful in obtaining the electric light. With one of these powerful machines driven by steam, an electric light of remarkable brilliancy is produced.

585. Electric Lighting by Magneto-electricity.— In Art. 554 we considered the electric light as produced by a voltaic battery, but experience has proved that to make this light of practical benefit and at the same time economical, the electrical energy must be derived from *dynamo-electric machines*. All these machines embody the general principle of a revolving armature, wrapped about with coils of wire, in front of the poles of a magnet, as described in the article on Magneto-electricity.

Probably the best machine for this purpose is the Brush magneto-electric generator, invented by CHARLES F. BRUSH, of Cleveland, O. For industrial use and illuminating large areas the Brush system of electric lighting is no longer an experiment but a substantial success, and is more extensively adopted than any other.

There are two kinds of electric lamps in use, the incandescent and the voltaic arc. The incandescent consists of a strip of platinum, carbon, or bamboo, placed in the circuit, which becomes white-hot when the current passes, and emits a brilliant light. The voltaic arc was described in Art. 554.

The Brush system uses the voltaic arc in preference to the incandescent, as being more economical and powerful for lighting streets, large parks, buildings, manufactories, halls, etc.

Gas-carbons in the arc are now, on account of their impurities, generally superseded by pure carbon, specially prepared and pressed; and to improve their conducting power they are sometimes coated with precipitated copper or nickel; this is the case with the Brush carbons.

It can be safely affirmed that for lighting large spaces the electric light has proved itself a success, but for domestic use, where small lamps with a steady, soft light are desired, the question has not yet been satisfactorily settled.

586. The Telephone. — The TELEPHONE is an instrument for transmitting sound by means of electric currents. Fig. 400 represents the form of the BELL telephone that is most generally adopted.

N S, seen in the section, is a permanent magnet, on one end of which is a coil of copper wire, *C*; in front of *C* is a

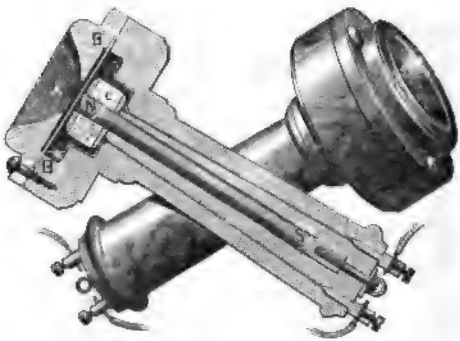

Fig. 400.

thin plate of soft iron, *BB*, called a diaphragm, and a mouth-piece, A. The position of the magnet in reference to the diaphragm is regulated by a screw at the right of *S*. The diaphragm is screwed down in place by the mouth-piece.

The ends of the coil pass alongside the magnet to the binding-screws at the right of the section, and are connected, one with the line-wire and the other with the ground, as in the telegraph, or with a return wire. The instruments at both ends of the line are precisely the same.

For practical purposes it is best to have two telephones at each station, so as to hold one to the ear while speaking through the other; it is also easier to hear with a telephone applied to each ear.

587. Action of the Telephone. — When a person speaks into the mouth-piece of the telephone the sound-waves of air strike against the diaphragm and cause it to vibrate. These vibrations produce an alteration in the magnetism of the permanent magnet, which induces electric currents in the wire coil. These electric pulsations, being transmitted through the line-wire to the distant helix in the second station, cause the diaphragm there to vibrate exactly like that at the sending station.

The waves of air that strike the ear from the second vibrating diaphragm, being complete reproductions of those that strike the first, give the same sounds. The *sound-waves* are not carried over the line-wire, but the pulsations of the electric current.

The sound that is reproduced in the receiving instrument becomes somewhat feeble, but still the characteristics of the person speaking are faithfully reproduced.

588. The Microphone consists of a small battery connected by means of wires with a telephone-receiver, and with the apparatus represented in Fig. 401. This apparatus consists of a vertical rod of carbon fitted loosely into two blocks, also of carbon; these are securely fastened to an upright framework; the wires that connect the carbon with the telephone and battery are seen at the left of the figure.

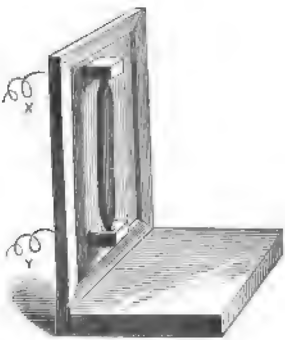

Fig. 401.

The sound produced by the walking of a fly on the base-board, or brushing of the softest feather, or faint ticking of a watch, are magnified to such an extent that they may be heard with distinctness miles away by the listener at the telephone. If the carbon be impregnated with mercury the microphone is considered more effective. To get the maximum effect with any particular instrument, the position of the carbon rod must be carefully adjusted by repeated trials. To prevent the interference of external vibrations the base-board should rest upon a cushion of wadding or india-rubber.

589. Thermo-electricity. — If two different metals are soldered together, and the free ends connected by wires with a galvanometer, the needle by its deflection will indicate the presence of the electric current, when heat is applied to the junction of the metals. When the junction is cooled, the needle will be deflected in an opposite direction. Electricity thus developed is called *thermo-electricity*. Such a combination of metals is called a *thermo-electric couple*.

The usual combination is a bar of bismuth soldered to one of antimony. When heat is applied, the current passes from the bismuth to the antimony; when cold, the reverse takes place. The bismuth is the positive bar with negative electrode, and the antimony the negative bar with positive electrode.

590. Thermo-electric Pile, or Battery. — By connecting a number of thermo-electric pairs (Fig. 402) we can form a *thermo-electric pile*, or *battery*, sometimes called *thermo-electric multiplier*. In this way we get a more powerful current than with a single pair. The positive pole, a, and the negative, b, connect by wires with the galvanometer.

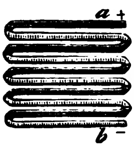

Fig. 402.

A large number of these pairs can be arranged in a compact form (Fig. 403), each pair and layer being carefully insulated by varnished paper. The whole is then enclosed in a framework of some non-conducting material. Such an apparatus as this constitutes the most delicate test for heat that has been devised. Some are so sensitive that the heat from the body of a fly walking over them will deflect the needle of the galvanometer.


Fig. 403.

If heat be applied to both faces of the pile, opposite currents will be produced, and they will neutralize each other if the temperature of both sides is kept alike, and no current results; but if one side is warmer than the other a current is produced. The current is thus due to the *difference* of temperature between the opposite faces of the multiplier.

The multiplier was used by MELLONI with great success in demonstrating the phenomena of radiant heat. For the purpose of concentrating the heat-rays upon the pile a cone is employed, as represented in Fig. 404.

Fig. 404.

591. Animal Electricity.—

Certain fishes possess the power of imparting a shock that compares in intensity with that of a powerful Leyden jar. Such fishes are called electrical fishes, the most interesting of which are the electrical eel of South America, and the torpedo, which is a native of the Mediterranean.

The shocks given by electrical fishes are due to electricity generated in the body of the fish. MATTEUCI showed that sparks could be obtained from the fish, and also that the galvanometer is affected when one of its wires is brought into connection with the back of the fish and the other with its abdomen. In all cases the shock is voluntary, and serves as a means of defence against enemies.

Summary.—

- *Induction by Currents.*
  - Illustrated by the Galvanometer.
  - Induced Currents produced by Primary and Secondary Coils.
  - Illustrated by Figure.
  - Laws of Induced Currents.
- *Induction Coils.*
  - Definition.
  - Construction explained by Figure.
  - Mode of Operation.
  - Use in Treatment of Diseases.
  - Ruhmkorff's Coil. — Its Power.
  - Geissler's Tubes.
- *Magneto-electricity.*
  - Definition.

Magneto-electricity (continued).

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Produced by Coil containing Soft Iron Bar and Magnet.

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Mode of Operation.

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Uses of these Machines.

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The Telephone.

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The Microphone.

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Thermo-electricity.

How Produced.

Thermo-electric Couple.

Thermo-electric Pile, or Battery.—Illustrated by Figures.

How the Battery works.

Animal Electricity.

PROBLEMS.

WEIGHTS AND MEASURES.

1. How many miles in 20 kilometers? In a cubic meter of water how many gallons? In 10 bushels, how many liters? What is the side of a square that contains 278,784 square decimeters?

2. Find the weight in kilograms of 10 gallons of water. In 896 millimeters, how many inches?

3. A box measuring 10 centimeters in each direction will hold how many liters, and is what portion of a cubic meter?

4. Reduce 5 pints to liters and cubic centimeters.

UNIFORM MOTION.

5. A railway train is moving uniformly at the rate of 30 miles per hour; what is its velocity in feet per second?

6. A locomotive runs 40 kilometers in $1\frac{1}{2}$ hours; what is its velocity per second in meters?

7. From two places, m and n, 30 kilometers apart in a straight line, two persons, A and B, start at the same time towards each other; A moves with a velocity of 3 meters per second, B with a velocity of two meters; at what distance from m and n will they meet, and after what time?

MOMENTUM AND STRIKING FORCE.

8. An iron ball weighing 20 pounds moves with a velocity of 100 feet per second, and a second ball weighing 5 pounds moves with a velocity of 400 feet per second; required the momentum and striking force of each ball.

9. A body weighing 200 pounds moves with a velocity of a mile in 14 seconds; what must be the weight of a body moving 6 feet per second to have the same momentum as the former?

10. A locomotive weighing 20 tons is moving with a velocity of 60 kilometers an hour; what is its momentum? How does it compare with a ship weighing 2,000 tons moving with a velocity of a decimeter per second?

11. Which will cause the most destruction: a 32-pound cannon-ball moving 1,200 feet per second, or a battering-ram weighing 12,000 pounds moving at a rate of 30 ft. per second?

12. If a pile-driver weighing 2,000 pounds, raised 25 feet, strikes with a given force, to what height must it be raised to produce an effect three times as great,

13. A train of cars moves 30 miles an hour; how much greater or less force would be required to move another train weighing one half as much 60 miles an hour?

14. A rifle-ball moves at the rate of 1,500 kilometers an hour; a stone thrown from the hand weighing five times as much moves at the rate of 400 meters a minute: how do their velocities, momenta, and striking forces compare?

15. A train has been moving with a uniformly accelerated motion; at 12 o'clock its velocity was 15 miles an hour, at 20 minutes past 12 it was 45 miles an hour; required its velocity at 10 minutes past 12 o'clock.

16. Suppose a bullet to be fired into an immovable block with a certain velocity, and we double the velocity, how much is the destructive force increased?

17. Three forces are acting in the direction, $A\ B$, equal, respectively, to 3, 5, and 8 units. In the opposite direction, $B\ A$, four forces are acting, equal, respectively, to 4, 6, and 10 units; what are the intensity and direction of the resultant?

18. Find the resultant of two forces equal to 25 pounds and 40 pounds acting upon the same point at right angles.

19. Two forces equal to 64 and 96 kilograms act at a point (1) in the same direction, (2) in opposite directions, (3) at right angles; find the resultant in the three cases.

20. The resultant of two forces acting at right angles is 12: one component is 7; what is the other?

GRAVITATION.

21. A body weighs 5,000 pounds on the earth's surface; what will it weigh 2,000 miles above? 500 miles above?

22. What will the same body weigh 2,000 miles below the earth's surface? 500 miles below?

23. If two bodies weigh, respectively, 150 and 300 pounds at the surface of the earth, what is the difference of their weights at the centre of the earth? 5,000 miles below the surface? 2,000 below?

24. How far from the earth's centre must a kilogram-weight be placed to weigh only one gram? How far above the earth's surface?

25. If the sun were $1\frac{1}{2}$ times farther from the earth than at present, and its mass $\frac{1}{3}$ less, how would its attraction for the earth be affected?

26. A stone is dropped into a well, and is seen to strike the water at the end of two seconds; what is the depth of the well?

27. A body has fallen through the distance of a mile and a half; what was the distance passed over in the last second?

28. A falling body is observed to pass over 200 feet in 3 seconds; how long had it been falling when first observed?

29. A body when observed had been falling 5 seconds; how much space had been passed over at the time of observation?

30. How far will a body fall in $15\frac{1}{2}$ seconds? In the 17th second? In the 25th second?

31. At what distance above the earth's surface will a body fall in the 3d second 8 inches?

32. A stone is thrown vertically upward with a velocity of 50 meters; after what time will it return to its original position?

33. A body is projected upward with an initial velocity of $58\frac{1}{4}$ feet per second; how high will it ascend before it begins to return?

34. Through what space must a heavy body fall from rest to acquire a velocity of 150 feet per second? To acquire a velocity of 300 feet?

35. A body falls through a distance of 160 feet; find its velocity at that time. Find how long a time it will take to fall through the next 190 feet.

36. A stone thrown horizontally from a cliff is seen to strike the ground in 4 seconds; how high is the cliff from the spot where the stone falls?

37. A cannon-ball fired obliquely into the air strikes the ground in 5 seconds; how high did it ascend?

38. The length of an inclined plane is 300 feet, the height 75 feet; what time is required for a body to descend the plane?

39. A stone is thrown vertically downward from a height of 200 meters with a velocity of 15 meters per second; how long will it be in falling?

CENTRE OF GRAVITY.

40. If two bodies, weighing, respectively, 12 and 16 pounds, are connected by a bar, where is the common centre of gravity?

PENDULUM.

41. The length of a seconds-pendulum —

At New York	is	39.1012
" Paris	"	39.1285
" Greenwich	"	39.1398

What is the length of a pendulum at Paris to vibrate half-seconds? To vibrate half-hours?

42. If the length of a pendulum is 4 meters, what is its time of vibration at Paris?

43. How will the times of vibrations of two pendulums compare whose lengths are, respectively, $6\frac{1}{4}$ inches and $5\frac{1}{18}$ inches?

44. In what time at Greenwich will a pendulum a kilometer long make a vibration?

45. A pendulum two meters long makes 350 vibrations during a certain time; how many vibrations will it make in the same time if the pendulum contracts a centimeter?

46. A pendulum vibrates twice in $\frac{2}{3}$ of a second; how long is it?

47. One pendulum vibrates five times as fast as a second; what are the proportional lengths?

48. If the pendulum of a clock beating seconds at New York should expand $\frac{1}{1000}$ of its length, how many seconds would it lose each day?

ENERGY.

49. How many kilogram-meters are represented in raising 500 kilograms 10 meters high?

50. Which has the greater energy: a body weighing 100 pounds and having a velocity of 6 feet per second, or one weighing 6 pounds with a velocity of 100 feet? Represent the energy by numbers.

51. What is the work expressed in foot-pounds that is required to raise 500 pounds 10 feet high?

52. A locomotive weighing 20 tons, moving at the rate of 30 miles an hour, has how much energy?

53. What is the horse-power of an engine that will raise 100,000 pounds 500 feet in 2 minutes?

54. What is the horse-power of an engine that can raise 50,000 pounds 10 feet in 5 seconds?

THE LEVER.

55. From a lever of the first class 3 feet in length, a weight of 500 pounds is suspended $2\frac{2}{3}$ inches from the fulcrum; what weight at the other end will keep the lever in equilibrium?

56. In a lever of the second class 12 feet long, where must the fulcrum be placed in reference to the weight so that a power of half a pound may balance a weight of 10 pounds?

57. In a lever of the first class, the distance of the power from the fulcrum is 12 feet and from the weight to the fulcrum 4 inches; how much weight will a power of 1 gram balance?

58. In a lever of the first class, what weight will a power of 100 pounds balance, with a lever 16 feet long and weight 4 feet from the fulcrum? What would be the result with a lever of the second class?

59. Two men are carrying a weight of 300 pounds on a pole 8 feet long; where must the load be placed so that one will lift one third of the weight?

THE WHEEL AND AXLE.

60. The diameter of a wheel is 4½ feet and the axle 5 inches; what power is required to sustain a weight of 500 pounds?

61. The barrel of a capstan has a radius of 5 inches, the radius of a circle described by the hand-spikes is 5 feet; what power is necessary to raise an anchor weighing 1,200 pounds?

THE PULLEY.

62. In a system of pulleys the power is 100 pounds; how many movable pulleys are required to sustain a weight of 600 pounds?

63. What power is necessary to sustain a weight of 500 kilograms with 5 movable pulleys?

THE INCLINED PLANE.

64. On an inclined plane whose base is 15 feet and height 5 feet, what power acting parallel with the base will balance a weight of 3 tons?

65. With a plank 10 feet long, to what height can a man capable of lifting 150 pounds roll a barrel containing material weighing 500 pounds?

THE SCREW.

66. If the threads of a screw are one half an inch apart, what weight will a power of 100 pounds raise, acting at a distance of 5 feet from the axis of the screw?

67. What is the distance between the threads of a screw when a power of 50 pounds will raise 2 tons acting on a handle 4 feet long?

HYDROSTATICS.

68. What is the pressure on the bottom of a cistern 50 feet long, 15 feet high, and 25 feet wide? What is the pressure on each side?

69. Suppose in the hydrostatic press the area of the smaller cylinder is 3 square inches and the larger 1,000 square inches; suppose, also, the pump-handle to be 4 feet long and the piston to be 3 inches from the fulcrum; what pressure will be exerted on the larger cylinder if a power of 500 pounds be applied to the end of the pump-handle?

70. The whole pressure on the bottom of a pail of water, the radius of which is 25 centimeters, is 50 kilograms; what is the depth of the water in the pail?

71. What height must a column of mercury have to balance a column of water 20 feet high?

72. A body weighs 30 grams in air and 20 in water; what is its specific gravity?

73. What is the weight of a cubic foot of gold? Of platinum? Of iron? Of zinc?

74. The specific gravity of cork being .24, how much must be used to float a man, his specific gravity being 1.12?

75. What is the weight of a bar of gold 30 centimeters long, 4 wide, and 12 thick?

76. A cylinder of oak is 30 centimeters in diameter and 3 meters long; the specific gravity of the wood is 1.17; what is the volume and weight of the cylinder?

77. How much bulk must a hollow vessel of iron occupy, weighing 2 tons, that it may float with half its bulk immersed in water?

78. A body whose specific gravity is 3.53 weighs 5 pounds in water; find its weight in air.

79. An empty vessel weighs ½ a pound, filled with water it weighs 1½ pounds, filled with another liquid it weighs 1¼ pounds; what is the specific gravity of the liquid?

SOUND.

80. A cannon-flash is seen, and in 10 seconds the report is heard; how far away is the cannon?

81. Three seconds elapse between a flash of lightning and a corresponding peal of thunder; what is the distance of the place of origin?

82. How many miles will sound travel in an hour? How long will it take it to go around the earth?

83. A tuning-fork gives sound-waves 1 meter in length; how many vibrations per second does it make?

84. A shot is fired before a cliff, and the echo is heard in 7 seconds; what is the distance of the cliff?

85. The density of oxygen is about sixteen times that of hydrogen; show that the velocity of sound in hydrogen ought to be about four times that in oxygen.

REVIEW QUESTIONS.

PROPERTIES OF MATTER.

1. What is physics? What are physical agents? Name them. **2.** Define a body; a material point; a molecule; an atom. **3.** How are molecules kept in place? **4.** What is the mass of a body? Density? Give examples of dense and rare bodies. **5.** How are bodies divided? Define solids, liquids, and aeriform bodies. How is the term fluid applied? **6.** What are the general properties of bodies? **7.** Define extension. **8.** What are English measures? **9.** Explain the metric system. **10.** What are the metric measures of length? of surface and volume? **11.** What are the metric measures of capacity? **12.** Define weight. **13.** Give the metric table of weight. **14.** Define impenetrability. Examples. **15.** Define inertia. Examples. **16.** Define porosity. Define sensible and physical pores. **17.** Define divisibility. Examples. **18.** Define compressibility. Experiments. Explain compressibility of gases, liquids, and metals. **19.** Define expansibility. Expansion of gases, liquids, and solids. Give experiment. **20.** Define elasticity. Examples. How can elasticity be brought into play? What bodies are most elastic? How is it shown that ivory is elastic? Explain the experiment. Explain some of the applications of elasticity.

21. Define molecular forces. Name them. **22.** Define cohesion and adhesion. Examples. Explain solution. Examples. **23** Explain capillarity. Experiments. **24.** Give some applications of capillarity. **25.** Define absorption. Examples Carbon, spongy platinum, animals and vegetables, paper. Application. Wood Application. **26.** Define osmose, endosmose, and exosmose Explain experiment Examples. **27.** Define dialysis. To what substances can dialysis be applied? **28.** Define tenacity. How measured? What bodies are most tenacious? Give table What is the form of greatest strength? Application to grasses, quills, bones, etc. How do we increase the tenacity of metals? **29.** Define hardness. Give scale of hardness of minerals. How do we test the relative hardness of bodies? Examples. What are brittle bodies? What is the effect of alloying bodies? Explain the process of polishing. How is the diamond polished? **30.** Define ductility. Examples of plastic bodies. Examples of ductile metals. **31.** Define malleability. Effect of temperature. How is gold formed into sheets? Lists of metals malleable under the hammer and rolling-mill.

MECHANICAL PRINCIPLES.

32. Define mechanics. **33.** Explain rest and motion. Explain relative and absolute rest and motion. Illustrate by examples. **34.** Define uniform motion. Example. Define velocity. Example. **35.** Define varied motion. When accelerated and when retarded? Examples. Define uniformly accelerated and retarded motion. Examples.

36. On what are the principles of mechanics based? **37.** Give Newton's First Law of Motion. Illustrate. **38.** Give Newton's Second Law. What three elements determine a force? Define each. How represented? **39.** Define simple and compound motion. Define resultant. Illustrate. Define compounds. **40.** Explain the parallelogram of forces. Define composition and resolution of forces. Illustrate by figure. **41.** Explain the flight of a bird. **42.** Explain the sailing of a boat. **43.** Explain the resultant of parallel forces. When the forces act in the same and opposite directions. **44.** Explain the composition of more than two forces. **45.** Define momentum. Illustrate. Rule for finding momentum. Examples. **46.** Explain collision of bodies. Illustrate. The effect is proportional to what? Illustrate. **47.** Define striking force. Proportional to what? Illustrate the difference between momentum and striking force. **48.** Define action and reaction. What is Newton's Third Law? **49.** Illustrate reaction in non-elastic bodies. **50.** Illustrate reaction in elastic bodies. Give some familiar examples. **51.** Explain reflected motion. Define lines and angles of incidence and reflection. Give the law of reflected motion. Illustrate by figure. **52.** Explain the centrifugal and centripetal forces. Illustrate by examples and figure. How does the body move when the centripetal force is destroyed? Explain the experiment with ivory balls. **53.** Give some effects of the centrifugal force. Effect on the earth. Explain the experiment. Explain the tendency of bodies to revolve about their shortest axis. **54.** Define the gyroscope. Explain figure.

55. Define the force of gravity; weight; universal gravitation. Explain the law of universal gravitation. Give the law of Newton. Explain further by figure. Why do not two bodies come together resting on a table? **56.** Explain the effect of gravitation on the planets. **57.** What is the law of the force of gravity? Why is gravity different at different places on the earth's surface? **58.** Define a vertical line. Illustrate by figure. Define a horizontal line. Illustrate What instruments are based upon these lines? **59.** What is the difference between weight and gravity? How is each determined? **60.** Define the centre of gravity. Explain. What is the line of direction? Where is the centre of gravity in solids of regular figure and uniform density? Examples. In sheets of uniform thickness and density? How is the centre of gravity found in surfaces of irregular outline? How found in any solid? When not within the body, how is it found? **61.** When is a body in equilibrium? When a body rests on a point, where must the centre of gravity be? When it rests on two points? Example. When on three points? Example. **62.** What are the three cases of equilibrium? What is stable equilibrium? Illustrate. Examples. What is unstable equilibrium? Illustrate What is neutral equilibrium? Illustrate. Examples of the three kinds of equilibrium with the cone. **63.** What bodies are the most stable? Explain the stability of the towers of Pisa and Bologna. How do men and animals maintain a stable position? Illustrate. **64.** Give the three laws of falling bodies. How is the first law verified? Explain the reason of the second law. Third law. What is the rule for finding the velocity acquired by a falling body at the end of any given time? Example. What is the rule for finding the space passed over during any given second of the descent? Example. What is the rule for finding the whole distance traversed by a falling body in a given time? Example. **65.** Explain Galileo's method for verifying the laws of falling bodies. **66.** What is the effect on a body thrown perpendicularly upward? How do we find the number of seconds it will continue to rise? Example. How do we find the whole distance it will rise? Example. **67.** Define a projectile. Illustrate by figure when a ball is thrown horizontally. Illustrate the path of a ball by figure, fired obliquely, at different angles. **68.** When will a ball fired horizontally reach the ground? When, if fired obliquely upward? **69.** Define the pendulum. What causes the pendulum to vibrate? Explain the action in detail. What is oscillatory motion? What is an oscillation or vibration? What is its amplitude? What effect has the air on vibration? **70.** What is a simple pendulum? Is it real or ideal? What is a compound pendulum? Explain its construction. **71.** Give the four laws of the vibrations of the pendulum. How are these laws deduced? How is the first law verified? Second law? Limitation. Define isochronism. When are vibrations isochronical? Who discovered the pendulum, and when? **72.** Explain the centres of suspension and oscillation. **73.** What is the principal use

of the pendulum? What is the motor in a clock? Explain the action of the pendulum as a regulator. What effect have variations of temperature on the pendulum? How are these effects compensated in nice clocks? How in common clocks? Why do clocks lose time in summer and gain time in winter? **74.** How are compensation pendulums made? Explain the mercury pendulum. Explain the gridiron pendulum. What is the relative expansion of brass and steel? **75.** What is the length of the seconds pendulum at the equator? at New York? at Spitzbergen? Explain the cause of this variation.

76. Define work. Application of the term. Illustrate. **77.** Explain measurement of work. Define foot-pound. Kilogram-meter. Rule for finding example. **78.** Explain horse-power. Apply to machines. **79.** Define energy. Illustrate. Rule for finding amount of energy. **80.** Explain kinetic and potential energies. Illustrate.

APPLICATION OF PHYSICAL PRINCIPLES TO MACHINES.

81. Define a machine; power; weight. **82.** Define motor. Examples. **83.** What is the object of machines? Can a machine create power? What are hurtful resistances? Their effect? **84.** Work implies what? What measures the quantity of work? The work of the power equals what? Illustrate. Give the three general laws of machines.

85. Name the mechanical powers. **86.** Use of cords, bands, and belts? **87.** Define the lever; fulcrum; power; weight. What are the lever arms? Illustrate. Describe the three classes of levers. **88.** Give the law of the lever. Examples. **89.** Examples of levers. **90.** Explain weight between two supports. **91.** What are compound levers? Rule. Example. **92.** Define the balance. Explain the parts. How are bodies weighed? **93.** Name and illustrate three requisites for a good balance. **94.** How is a balance to be tested? **95.** How may a body be weighed correctly by a false balance? **96.** Explain and illustrate the steel-yard. **97.** Explain the wheel and axle. Show the principle of lever. Give rule. **98.** Explain the windlass. **99.** Explain the capstan. **100.** Explain the differential windlass. **101.** What is a train? driver? follower? **102.** Explain the modes of connection and illustrate. **103.** What is the law of wheel-work? Examples. **104.** Define the pulley. **105.** Explain the fixed pulley. **106.** Explain the movable pulley. Use of fixed pulleys? **107.** Explain and illustrate combinations of pulleys. Give the law. Examples. **108.** Define the inclined plane. Explain its principle. What is the ratio of power to the weight? Illustrate. Examples. **109.** Explain the wedge. Why cannot we accurately estimate the power of the wedge? Use of the wedge? Examples. **110.** What is the screw? its thread? its nut? Illustrate the use of the lever combined with the screw. **111.** What is the law of the screw? **112.** Describe the endless screw. Its uses.

113. What is friction? How caused? Sliding and rolling? **114.** How is friction measured? Illustrate. What facts have been ascertained about friction? **115.** Name some advantages of friction. **116.** How does the stiffness of cords produce friction? How lessened? **117.** Explain atmospheric resistance.

THE MECHANICS OF LIQUIDS.

118. Define hydrostatics and hydrodynamics. **119.** Name the properties common to all liquids. Illustrate. **120.** What is the principle of Pascal? Illustrate with bottle and cylinder. **121.** Explain pressure due to the weight of liquids. **122.** Does the pressure on the bottom of a vessel depend upon the shape of the vessel? How shown? Explain the experiment in detail. **123.** Explain the hydrostatic bellows. **124.** How is lateral pressure demonstrated? Describe the reaction wheel. Explain its action. **125.** How is upward pressure demonstrated? Illustrate. **126.** What is Pascal's experiment? **127.** What is the principle of the hydraulic press? Describe in detail. Illustrate its power by example. What are its uses?

128. When is a solid in equilibrium? a liquid? If the liquid is acted on by other forces than gravity, what is the result? **129.** What is a level surface? Illustrate. **130.** What are the conditions of equilibrium in communicating vessels? How demonstrated? **131.** What are the conditions of equilibrium in liquids of different densi-

ties? How demonstrated? **132.** Explain equilibrium of heterogeneous liquids. How shown?

133. Explain the water-level. How used? **134.** Explain the spirit-level. How used? Applications. **135.** Explain springs, fountains, and rivers. **136.** Explain artesian wells. Illustrate. Examples. Oil-wells.

137. How are submerged bodies pressed? Illustrate. Give the principle of Archimedes. **138.** Explain the hydrostatic balance. **139.** Explain the cylinder and bucket experiment. What is the story of Archimedes? **140.** When a body is plunged into a liquid, what three cases arise? Explain each. Define plane of flotation. Why does a saucer float on water? **141.** Illustrate the principles of flotation by experiment. **142.** Explain the swimming bladder of the fish. What is its action? **143.** Explain swimming.

144. Define specific gravity. Illustrate. What is taken as a standard? How do we find the specific gravity of a body? **145.** How do we find the specific gravity of a solid by the hydrostatic balance? Rule. Example. How do we find the specific gravity of a solid that floats on the water? Examples. By Nicholson's hydrometer? By a flask? **146.** How do we find the specific gravity of liquids by Fahrenheit's hydrometer? by a flask? Application of specific gravity. **147.** Describe Beaumé's areometer. How is it graduated? Use? **148.** Describe the alcoholmeter How graduated? Use?

149. Explain the flow of liquids from orifices. The velocity increases in proportion to what? Illustrate. When is the range of a horizontal jet the greatest? **150.** The volume of a liquid discharged is equal to what? Example. Explain the vena contracta. **151.** Explain the flow of liquids through pipes. Illustrate. **152.** Explain the flow of rivers; the resistance of friction.

153. Explain the energy possessed by water collected in reservoirs, etc. What are the forces that turn water-wheels? **154.** Explain the undershot wheel. **155.** Its power. Explain the overshot wheel. Its power. **156.** Explain the breast-wheel. Its power. **157.** Explain the turbine wheel. Illustrate. How great is its power?

158. Explain Archimedes' screw. **159.** Explain the chain-pump. **160.** Explain the hydraulic ram. Illustrate its action.

PNEUMATICS.

161. What are gases and vapors? How do they differ from liquids? What is the difference between a gas and a vapor? **162.** The atmosphere is the type of what? What is its color? Composed of what? Sources of carbonic acid in the air? The relation of plants to oxygen and carbonic acid? **163.** Illustrate the expansive force of air **164.** Prove that air has weight. **165.** Explain atmospheric pressure. Illustrate. **166.** Show the unbalanced force of the air by bursting a membrane and by stretching rubber. **167.** Illustrate the force of the air with the Magdeburg hemispheres. **168.** Illustrate the upward pressure of the air by experiments with tumbler and piston with weight attached. **169.** What is the pressure of the atmosphere on a square inch? Describe Torricelli's experiment. How shown that the pressure is 15 pounds on an inch? What unit of pressure is adopted for all gases and vapors? Example. **170.** Describe Pascal's experiments in detail, and his mode of reasoning. What conclusion is derived from Pascal's experiments? **171.** What is a barometer? What is its principle? **172.** Describe the cistern barometer. Where is the zero point of the scale? How is it regulated in accurate barometers? How is the height of the barometer determined? **173.** Describe the siphon barometer. How do we find the height of the barometer? How are oscillations obviated? **174.** Describe the wheel barometer. Illustrate its action. Why inaccurate? **175.** What is the principle of the aneroid barometer? Explain its action. **176.** What are the causes of barometric fluctuations? Illustrate. **177.** Explain the barometer as a weather indicator. What rules are generally trustworthy? **178.** On what principle is the barometer used for measuring heights? Give rule. **179.** What is the pressure of the atmosphere on the human body? How resisted? How is it shown that the tissues of the body contain gases? Principle of cupping?

180. What is Mariotte's law? Consequence? **181.** Prove the law by Mariotte's tube.

182. Who invented the air-pump? When? Describe the air-pump. Explain its action. **183.** Describe the siphon gauge. Explain its action, **184.** Explain Sprengel's air-pump and its action. Principle of the filter-pump. **185.** Give some experiments with the air-pump. **186.** Explain the use of the air-pump in concentrating syrups. Explain pneumatic tubes and their use. **187.** Explain the condenser and its action. **188.** Give some applications of condensed air. How are persons affected in dense air? **189.** How is condensed air applied to tunnelling and mining? Explain some of the machines used in drilling. **190.** What are the advantages in the use of compressed air? **191.** What is the principle of the fountain? Describe Hero's fountain and explain its action. **192.** Explain the construction and use of the atmospheric inkstand. **193.** Define the water-pump. What are the principles employed? **194.** Describe the lifting-pump. Illustrate its action. What is the lowest limit of the play of the piston? **195.** Describe the forcing-pump. Illustrate its action. **196.** Describe the forcing-pump with air-chamber Explain its action. **197.** What is the fire-engine? Describe it and explain its action. How operated? **198.** What is the siphon? Its use in decanting? How is it prepared for use? Explain its action and the principle involved. How high can water be raised by a siphon? **199.** Explain adhesion of liquids and gases. How is Gifford's injector used? Explain the principle of adhesion by experiment.

200. What is the baroscope? Describe it. Explain its use. What is the principle of Archimedes? Examples. **201.** What is a balloon? How were balloons first made? What are fire-balloons? **202.** Balloons of the present day are filled with what? How are they made? How does the aeronaut know whether he is ascending or descending? Upon what principle does the balloon rise? Give the measurements of a balloon. Explain failure of attempts to direct its course. **203.** Explain the method of filling a balloon and making an ascent. **204.** Of what use are balloons? The greatest height attained? **205.** What is the parachute? Construction? Give the experiment of Wise. What is the use of the parachute? How is the parachute detached from the balloon?

ACOUSTICS.

206. Define acoustics. **207.** Define sound. How caused? Define sonorous; medium. Illustrate sound by a stretched cord. **208.** Explain sound-waves. What is meant by a condensed and a rarefied pulse? Illustrate the formation of sound-waves with tuning-fork and bell. Define velocity of sound. Wave-length. Illustrate. Define amplitude of vibration. **209.** Explain combinations of sound-waves. Examples. **210.** Explain coincidence and interference of sound-waves. Illustrate with tuning-fork. Example. **211.** Explain beats. Illustrate with tuning-fork. Rule. Examples. **212.** Prove that sound is not propagated in a vacuum. **213.** Give examples of the propagation of sound in liquids and solids. **214.** Give examples to show the velocity of sound in air Give an account of the experiment of scientists to find the velocity of sound in air Explain the relation of the density and elasticity of air to the velocity of sound. The velocity is proportional to what? **215.** Give the experiment of Colladon and Sturm in finding the velocity of sound in water. What is the velocity per second? **216.** What is the velocity of sound in solids? How proved? Why is the velocity of sound in solids and liquids greater than in air? **217.** Explain reflection of sound and echoes. Illustrate. What is necessary to get an echo? When is an echo monosyllabic? dissyllabic? etc. What are multiple echoes? How is sound wasted? Examples. **218.** Explain acoustic clouds. Illustrate. **219.** What is resonance? Illustrate. **220.** Explain refraction of sound. Illustrate by experiment with the watch. **221.** Upon what does the intensity of sound depend? How does it vary? Illustrate how sound may be modified. **222.** Explain intensity of sound. Give Biot's experiment. What are speaking-tubes? **223.** Explain the speaking-trumpet. What is the theory of its effect? **224.** Explain the ear-trumpet and its use. How does it act upon the sound-waves?

225. What causes a musical sound? **226.** A noise? Examples. Illustrate by Savart's wheel. **227.** Upon what does pitch depend? Illustrate. **228.** Give the cause of grave

and acute sounds. **229.** What is the use of the siren? Describe it in detail. Explain its action. **230.** Explain how we determine the rapidity of the vibrations of the sonorous body. **231.** Explain how we find the length of a sound-wave. **232.** How are cords made to vibrate? What are transversal vibrations? They depend upon what? **233.** Describe the sonometer. Name and illustrate the four laws of transversal vibrations. **234.** Explain the verification of these laws. **235.** Explain the formation of nodes. **236.** Illustrate Melde's vibrations of a string. **237.** How can strings or wires be made to vibrate longitudinally? How does their pitch compare with that of transversal vibrations? The shorter the wire, how are the vibrations? Prove. Illustrate these vibrations by experiment. **238.** Explain sympathetic vibrations. Examples. **239.** Explain vibration of plates with sand. How are Chladni's figures produced? **240.** Explain overtures, or harmonics. What is a fundamental tone? **241.** What is meant by quality, or timbre? Illustrate. **242.** What is meant by the musical scale? What is the gamut, or diatonic scale? How are the notes named? Give the tables expressing the relative vibration of each note of the octave, and the relative lengths of strings. Table of absolute number of vibrations. There are really how many notes in the diatonic scale? **243.** Define a musical interval. How do we find the numerical value of any interval? Give table of intervals. **244.** Define melody. Example. **245.** Define a chord; harmony. Example. Define discord. When do we have the simplest and most agreeable harmony?

246. What is the optical study of sounds? **247.** Explain Lissajous' representation of vibrations with single fork and mirror. **248.** Explain vibratory motions of two forks at right angles. Practical use of these principles. By what other method can these figures be produced? **249.** Give the construction of the kaleidophone. **250.** What is the object of Koenig's apparatus? Explain its construction. Explain its action in producing monometric flames. **251.** Into what two classes are stringed instruments divided? Give examples of each. **252.** How is sound produced in pipes? Give the method. What are the two forms of the mouth-pieces? **253.** What are pipes with fixed mouth-pieces? Give examples. Describe a section of one. Explain the action of the air in causing the sound. What is the difference between the nodes of an open organ-pipe and a closed one? Explain the nodes of an organ-pipe. Prove with sand. How shown with Koenig's capsule? **254.** What are reed-pipes? Give examples. Give the two kinds of reeds Describe the arrangement of a reed of the first kind. Explain its action. Explain the action of the free reed. **255.** Wind instruments consist of what? Illustrate their action. **256.** Explain sounding-flames. Illustrate by experiment. **257.** Explain sensitive flames. Illustrate. **258.** What kind of an instrument is the human voice? What are the vocal chords? How is the voice produced? **259.** Describe the parts of the ear. How is sound carried to the brain? **260.** What is the phonograph? Describe it. Explain its action. **261.** What is meant by energy of sound vibrations? Illustrate.

HEAT.

262. Define heat. **263.** Explain heat as a form of energy. What is cold? Explain the two theories of heat. Heat can be changed into what form? **264.** Describe the general effects of heat. What is internal work? external? How do heat and cold affect bodies? **265.** In gases, liquids, and solids, what is the order of expansion? Name and describe the kinds of expansion. **266.** How is linear expansion of metals shown? Expansion in volume? **267.** How is unequal expansion of metals shown? **268.** How is expansion of liquids shown? of gases?

269. Define temperature; sensible heat. Explain the difference between temperature and quantity of heat. **270.** What is a thermometer? Why cannot bodily sensations measure temperature accurately? What is the principle of the thermometer? What is the best thermometer for common use? Describe a mercurial thermometer. **271.** Describe the method of making a thermometer. **272.** Describe the method of graduation. **273.** Describe the centigrade, Réaumur's, and Fahrenheit's scales. What letters are used to designate the different scales? **274.** How are the degrees of one scale converted into those of another? Illustrate. Give the formulæ. **275.** How does the alcohol differ

from the mercurial thermometer? How is it graduated? Why? How filled? **276.** When is the alcohol preferable to the mercurial one? Why? When must the latter be used? Which is the slower in its action? **277.** What rule should be followed in using the thermometer? How should we get the temperature of a room? of the atmosphere? **278.** What is a differential thermometer? What are its two forms? Upon what principle are they based? **279.** Describe Rumford's, and explain its action. **280.** Describe Leslie's, and explain its action. What is the best instrument for measuring temperature? **281.** What is a pyrometer? What are the most important ones? What is the principle of each? Are they trustworthy? What arrangements are now used for measuring high temperatures? **282.** Explain absolute zero of temperature. Has it ever been realized? What is the greatest artificial cold produced at the present time? greatest natural?

283. What is the coefficient of linear expansion of solids? How determined by Lavoisier and Laplace? Give some results. What is the coefficient of superficial expansion and expansion in volume? How determined? **284.** Give some examples of the principle of expansion and contraction. **285.** Why are liquids more expansible than solids? What is absolute expansion? relative? Example. Which is generally observed? What is the coefficient of expansion of a liquid? **286.** At what temperature has water the greatest density? When does it freeze? Describe two methods of determining the maximum density of water. Explain the apparent exception to the law of expansion and contraction. Why is iron valuable for casting? Explain the consequences of the expansion of water when freezing. Example of the lakes in Switzerland. Why is water taken at 39.2° F. a standard? **287.** What bodies are most expansible? What is the coefficient of expansion of a gas? What was Guy Lussac's opinion? **288.** Give some applications of the expansion of gases. **289.** Upon what does the density of a gas depend? What do we take as a standard? How do we determine the density at any other pressure and temperature? Example.

290. What are the three methods of diffusion of heat? **291.** How is heat transmitted through space? Define radiant heat and rays of heat; undulatory or radiant energy. **292.** Give the four laws of radiant heat and their verification. **293.** Explain exchange of heat between bodies, and give example. **294.** What is reflection of radiant heat? Define the terms used. **295.** Give the laws of reflection. Describe the apparatus for verifying these laws. Explain the mode. **296.** Define a concave mirror. Define the term focus. Explain the experiment illustrating the action of concave mirrors. What is the advantage of parabolic mirrors? What is a burning mirror? Explain its use. **297.** Define good and bad reflectors. Explain Leslie's method of determining the reflecting power of different bodies. Give some results. Define the terms diathermanous and athermanous. Examples. What rays warm a body? **298.** Explain Leslie's method of determining the absorbing power of bodies What was the result? **299.** What is the radiating power of a body? Explain Leslie's method of determining it. Give the result of the experiment. **300.** What causes modify the radiating and absorbing powers of bodies? Effect of polish? of density? of direction of rays? of the source of heat? of color? **301.** Describe the radiometer. Explain its action. What is the supposed cause? **302.** Explain the absorbing power of gases. Examples. What is the connection between light and heat? **303.** Give some applications of the preceding principles. **304.** Define conduction; good conductors; bad conductors. Explain Ingenhousz's apparatus. How used? What are the respective conducting powers of solids, liquids, and gases? **305.** What is convection? Explain by experiment. How are gases heated? **306.** Give some applications of the preceding principles.

307. What is fusion? When does fusion take place? The melting-point is usually the same as what? Can the freezing-point be lowered? Is the melting-point the same for all metals? Examples. Are all bodies melted by the action of heat? Examples. **308.** Explain latent heat of fusion. What does latent heat strictly mean? What type of energy is it? Illustrate latent heat of fusion by example. Explain the action of latent heat on melting masses of ice; on freezing masses of water. **309.** Define congelation. How does the point of congelation compare with that of fusion? Illustrate. How does the heat given out in solidifying compare with that taken up in melting? Illustrate by exam-

ple. What liquids have never been frozen? Give some examples of the immense power exerted when a liquid passes from a liquid to a solid state. Explain regelation. **310.** What are crystals? What is crystallization? Examples. Give and explain the methods of crystallization. **311.** What is a freezing mixture? Example. Explain its action.

312. Define vaporization, evaporation, boiling, and sublimation. What two classes of liquids have we? Define each, and give examples. **313.** Illustrate the tension of vapors by experiment. Give some examples of the power of steam. **314.** Why do vapors escape from the surface of liquids? When the pressure is removed, what happens? Illustrate the principle by the experiment. What does the experiment show? **315.** When does vapor cease to form? **316.** Give four causes that accelerate evaporation. Give illustrations and applications of these causes. **317.** What is ebullition, or boiling? Explain the phenomena of boiling Give the two laws of ebullition. Illustrate. **318.** What are the principal causes that modify the boiling-point? Illustrate by examples. **319.** What principle does Papin's digester illustrate? Explain its construction and use. What causes explosion in steam-boilers? **320.** Who have measured the elastic force of vapors? What is proved? **321.** What is the latent heat of vaporization? Explain latent heat as a type of energy. **322.** Explain latent heat of steam by example. Illustrate by experiment. **323.** Give examples of cold produced by heat becoming latent. **324.** Explain the spheroidal state of a liquid. Illustrate by example. **325.** Why does evaporation produce cold in surrounding objects? How can we produce cold with sulphurous acid and the spheroidal state of a liquid?

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